Healthy Beaches for People and Fish:

Protecting shorelines from the impacts of armoring today and rising seas tomorrow

The Impacts of Shoreline Armoring on Beach Spawning Forage Fish Habitat in San Juan County

Tina Whitman and Sally Hawkins

Friends of the San Juans

February 2014

FRIENDS
OF THE SAN JUANS

Healthy Beaches for People and Fish

The goal of the *Healthy Beaches for People and Fish*: *Protecting shorelines from the impacts of armoring today and rising seas tomorrow* project is to improve the long-term protection of nearshore marine ecosystems by developing new technical tools and identifying management strategies that specifically address sea level rise and the cumulative impacts of shoreline armoring.

The *Healthy Beaches for People and Fish* project was completed by Friends of the San Juans in partnership with Coastal Geologic Services, Salish Sea Biological and the Washington Department of Fish and Wildlife in 2014. Project approach and work was guided by a technical advisory group, which included representatives from The University of Washington, United States Geological Survey, Puget Sound Partnership, Skagit River Systems Cooperative, Samish Indian Nation, San Juan County Public Works, San Juan County Salmon Recovery Lead Entity, The Tulalip Tribes, Padilla Bay National Estuarine Research Reserve and the Washington State Departments of Ecology, Natural Resources and Fish and Wildlife.

The project contained four distinct areas that informed management recommendations:

- A legal review of existing local, state and federal shoreline regulations and their ability to address sea level rise and cumulative impacts;
- Sea level rise vulnerability assessment for San Juan County;
- Forage fish spawning habitat research; and
- Surveys of coastal managers, regulators and researchers.

Reports and data products associated with this project can be found online at www.sanjuans.org/NearshoreStudies.htm and include:

Friends of the San Juans. 2014. Healthy Beaches for People and Fish: Protecting shorelines from the impacts of armoring today and rising seas tomorrow. Final Report to WDFW and the U.S. EPA. Friday Harbor, Washington.

Loring, K. 2013. Addressing Sea Level Rise and Cumulative Ecological Impacts in San Juan County Washington Through Improved Implementation and Effective Amendment of Local, State, and Federal Laws. Friends of the San Juans. Friday Harbor, Washington.

MacLennan, A., J. Waggoner and J. Johannessen. 2013. Sea Level Rise Vulnerability Assessment for San Juan County, Washington. Prepared by Coastal Geologic Services for Friends of the San Juans.

Whitman, T., D. Penttila, K. Krueger, P. Dionne, K. Pierce, Jr. and T. Quinn. 2014. Tidal elevation of surf smelt spawn habitat study for San Juan County Washington. Friends of the San Juans, Salish Sea Biological and Washington Department of Fish and Wildlife.

Whitman, T. and S. Hawkins. 2013. The impacts of shoreline armoring on beach spawning forage fish habitat in San Juan County, Washington. Friends of the San Juans. Friday Harbor, Washington.

This project has been funded in part by the United States Environmental Protection Agency under assistance agreement PC 00J29801 to Washington Department of Fish and Wildlife. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. Match funding for the project was provided by the Bullitt Foundation and the North Pacific Landscape Conservation Cooperative. In kind match provided by FRIENDS of the San Juans, Coastal Geologic Services, Salish Sea Biological and technical advisory group participants.

The Impacts of Shoreline Armoring on Forage Fish Spawning Habitat in San Juan County

Contents

Tables

Figures

Map Books

Appendices

Introduction

Forage fish play a key role in marine food webs, with a small number of species providing the trophic connection between zooplankton and larger fishes, squids, seabirds and marine mammals, including ESA listed species such as Chinook salmon and the marbled murrelet. Beach spawning forage fish, such as surf smelt (*Hypomesus pretiosus*) and Pacific sand lance (*Ammodytes hexapterus*), are threatened by land use activities along shorelines, where development is also concentrated.

Forage fish spawning areas in San Juan County (SJC) and throughout Puget Sound are especially vulnerable to the impacts of shoreline armoring. Sea level rise is expected to exacerbate the impacts of shoreline armoring on forage fish spawning habitat (Krueger et al 2010). In addition, sea level rise and other implications of climate change such as increased storminess are anticipated to result in the increased demand for new shoreline armoring, which will further compound forage fish spawning habitat loss and degrade the nearshore sediment sources or feeder bluffs that sustain nearshore habitats. The objective of this assessment was to investigate the cumulative effect shoreline armoring is having on the upper intertidal sand and gravel beach habitats required by two key forage fish in the Puget Sound region, surf smelt and Pacific sand lance. The geographic scope of the project was San Juan County, Washington. Generous funding for this research was provided by the Washington Department of Fish and Wildlife through the EPA's National Estuary Program and the Bullitt Foundation.

Background

With over 400 miles of marine shoreline located at the confluence of Puget Sound, Georgia Strait and the Strait of Juan de Fuca, the nearshore marine habitats of SJC play an important role in regional salmon and orca recovery efforts. Bulkheads and other shore modifications that bury habitat and limit bluff erosion and littoral sediment transport have led to major changes in sediment supply and associated changes in beach and habitat stability. The cumulative impact of human modifications to the shoreline may be far-reaching in terms of both habitat and existing human activities, particularly in the face of anticipated increases in the rate of sea level rise and storm induced erosion. Coastal geomorphic processes create and maintain the nearshore habitats upon which many Puget Sound species of concern rely, including forage fish spawning areas, and juvenile salmonid rearing and migratory habitats, among others (Fresh 2006, Penttila 2007, Johannessen and MacLennan 2007).

Shore modifications, almost without exception, impact the ecological functioning of nearshore coastal systems. The proliferation of these structures has been viewed as one of the greatest threats to the ecological functioning of coastal systems (Thom et al. 1994). Modifications often result in the loss of the very feature that attracted coastal property owners in the first place, the beach (Fletcher et al. 1997). With bulkheading and other shore modifications such as filling and dredging, net shore-drift input from bluffs is reduced and beaches become "sediment starved." The installation of structures typically results in the direct burial of the backshore area and portions of the beach face, resulting in reduced beach width (Griggs 2005) and loss of habitat area (Bulleri and Chapman 2010). Beaches also become more coarse-grained as sand is winnowed out and transported away. The beach is often converted to a gravel beach which does not provide the same quality of habitat as a finer grain beach (Thom et al. 1994, MacDonald 1994). Large woody debris (LWD) is usually also transported away from the shore following installation of bulkheads, with corresponding changes in habitat (Tonnes 2008).

Habitats that are substantially impacted by shore modifications include forage fish (such as surf smelt and sand lance) spawning habitat. These habitat areas are only found in the upper intertidal portion of fine gravel and sand beaches, with a high percentage of 1-7 mm sediment (Penttila 1999), which is fine gravel (smaller than pea gravel) to coarse sand. Sand lance require 0.5-3.0 mm sediment for spawning. Beach sediment coarsening can also affect hard-shell clam habitat, by decreasing or locally eliminating habitat. A recent study by C. Rice (2006) documented the effects of shoreline modifications on Puget Sound beaches on surf smelt mortality. Results showed that anthropogenic alteration of the shoreline typically makes beaches less suitable for surf smelt embryo survival when compared with unmodified shores (Rice 2006). Loss of marine riparian areas is commonly associated with shoreline development and anthropogenically modified shores.

Shoreline modification was identified as a top threat to the SJC marine ecosystem (SJC Marine Stewardship Area Plan 2007) and protection of unmodified habitat was a primary focus for the San Juan Initiative's ecosystem research. In 2007, FSJ completed an *Analysis of Shoreline Permit Activity in San Juan County (1972-2005)* and found that over 300 permits are granted each year for shoreline structures, excluding houses (Whitman 2007). The analysis also found that no-net-loss and sensitive areas regulations adopted in the 1990's have not reduced the amount of shoreline permits granted that impact priority nearshore habitats including eelgrass and documented forage fish spawning habitats (Whitman 2007). Permits for expansion of existing armoring and new armoring of known surf smelt and Pacific sand lance spawning habitats continue to be granted in San Juan County by both county and state regulators.

In 2009, FSJ conducted a field-based inventory and mapping project of shoreline modifications for the 408 miles of marine shoreline within SJC. Results show that the current level of impact to shorelines is much higher than previously believed and that the vast majority of impacts are associated with residential shoreline development. Nearly 4,000 individual modifications were mapped, photographed and described (size, material, condition, tidal elevation) and include: 710 armored beaches, 472 docks, 32 groins, 55 marine railways, 70 improved boat ramps, 50 marina/jetty/breakwater, 425 pilings (not associated with another structure such as a dock), 1914 buoys and floats and 191 "other" beach structures (boathouses, stormwater outflow pipes, patios etc.).

Over 18 miles of SJC's total shoreline is armored; and 22.5% of sand and gravel beaches are armored.). As documented by the San Juan Initiative's Case Study (Johannessen and MacLennan 2008), there was a predominance of shore modifications along not just feeder bluffs but also along transport zones, accretion shoreforms and pocket beaches, which all provide habitat for important marine species. The location of most modifications along non-rocky shorelines means that impacts are concentrated in areas important to forage fish spawning habitat and habitat forming processes. With just ten miles of documented forage fish (surf smelt and Pacific sand lance) beach spawning habitat in SJC, improved protections are needed to ensure maintenance of these habitats over the long term.

Process-based restoration and protection has been recognized as the ideal means of restoring Puget Sound nearshore environments (Leschine and Petersen 2007, Johannessen and MacLennan 2007). Processed-based restoration attempts to restore and protect those self-sustaining processes that support the ongoing maintenance of habitats on a landscape scale. Eroding bluffs (commonly referred to as "feeder bluffs") contribute sediment to net shore-drift cells (along shore sediment sub-systems); replacing sediment that is continuously transported to maintain down-drift habitats such as spits and pocket estuaries. Protecting and enhancing physical processes along Puget Sound area beaches and bluffs is essential to sustaining, preserving, restoring and creating more resilient nearshore habitats (Shared Strategy 2005). The connections between coastal processes and nearshore habitats is complex and occurs at multiple spatial and temporal scales, all of which require adequate policy language to effectively protect or manage these resources.

The overall goal of the project was to investigate the cumulative effects of shoreline armoring on the upper intertidal beach habitats required for spawning by surf smelt and Pacific sand lance in San Juan County. The project's objectives were to:

1. Explore relationships between shoreline ownership, development, armoring, and forage fish spawn habitat at the county scale.
2. Quantify likely impacts of shoreline armoring on forage fish spawning habitat and habitat forming processes.
3. Provide quantitative information that supports improved protection of beach spawning forage fish habitat through voluntary and regulatory means at both the plan (landscape) and project (site) scale.

Methods

Geographic Information Systems Analysis: To better understand current conditions in San Juan County, multiple, spatially explicit analyses were conducted using a combination of existing countywide Geographic Information Systems (GIS) shoreline habitat, modification and development data layers and geodatabases. Primary data layers included:

- Documented forage fish spawn habitat (Friends of the San Juans and the Washington Department of Fish and Wildlife 2004);
- Potential forage fish spawn habitat (Friends of the San Juans 2011);
- Geomorphic shoreform (Friends of the San Juans 2011);
- Drift cell (Coastal Geologic Services 2010);
- Shoreline armor and groins (Friends of the San Juans 2010);
- Marine riparian vegetation (Friends of the San Juans 2011);
- SJC parcel data: ownership, building value, development status (San Juan County GIS Library and Assessor 2013);
- Roads (San Juan County GIS Library 2011); and
- Building footprint (San Juan County Public Works 2012).

Multiple, intermediate analyses were conducted using these spatial data sets, linking shoreline tax parcels to geomorphic shoreforms and the habitat and modification data already linked with shoreform through past salmon recovery efforts for the archipelago (Whitman et al 2012). Details on GIS methods are provided by topical section below as well as in Appendix A. GIS Data and Methods.

Beach Slope Study: New data on beach slopes was developed for the project by Coastal Geologic Services (CGS) to support quantitative analysis of the direct burial of forage fish spawn habitat by armor. Existing GIS data (FSJ 2010) provided information on armor location, length and toe elevation, but beach slope data was needed to accurately evaluate the area of intertidal habitat lost, not just linear feet or miles. The CGS beach slope study used a combination of new field surveys, existing physical survey data and GIS models to characterize beach slope based on a combination of geomorphic shoreform, exposure (fetch) and orientation. The same classification was applied to shoreforms analyzed in this cumulative impact assessment, and mean slopes were used to determine vertical width of beach distance in the calculation of buried area. Detailed slope characterization results are provided in Appendix B. Beach slope characterization for San Juan County shoreforms.

Permit Trend Analysis: A minor component of the analysis included an assessment of San Juan County bulkhead permit trends. Analysis of permit activity for bulkheads was conducted using the San Juan County permit database (SJC 2010). These results provide information on permit trends at the county scale. Permit trend results were not mapped or associated with known forage fish spawning habitat as armor data from the field-based inventory of shoreline modifications completed in 2009 provides a more accurate reflection of on-the-ground conditions, due to the fact that many structures are unpermitted and only a portion of the permit records in the database include spatially explicit information.

Overall analysis results are shown as counts and lengths for shoreline parcels and shoreforms at the countywide scale, as well as for two primary subsets of the county's shoreline parcels: documented forage fish spawn and potential forage fish spawn. Parcel scale data from the San Juan County Assessor provided the fine scale structure for the baseline data. Parcels were then tied through spatial proximity to geomorphic shoreforms, which allowed extensive habitat (forage fish spawning, riparian) and modification (armor location, toe elevation and length; groin location) data tied to shoreform from a previous salmon recovery strategic planning effort to also be considered at the parcel level.

Overview approaches of each of the major spatial analyses conducted with existing spatial data sets in GIS are described below. For more detailed GIS methodology, please refer to Appendix A. GIS Data and Methods.

Countywide Analysis of Development Patterns: Shoreline parcels were associated with geomorphic shoreform type, documented and potential forage fish spawning habitat and armor in GIS using compound spatial selections based on congruency of features. Parcel level shoreline development patterns were analyzed in a variety of ways, including ownership, development status, building footprint location and building value; these spatial variables were then linked to shoreform, shoreline armoring and forage fish spawning habitat. Results were conducted at the county scale, as well as for the subset of the county with forage fish spawning habitat. Ownership was broken into multiple categories, including conservation ownership defined as parcels in San Juan Preservation Trust or San Juan County Land Bank easement or ownership and enrollment in the Open Open Space incentive program. Public ownership was defined as all County, State, and federal ownership, as well as educational ownerships, as categorized by the San Juan County Assessor. Private, developed parcels and private, not yet developed parcels were identified based on a combination of San Juan County assessor land use codes and assessed building values. The location of structures on shoreline parcels were classified into distance bands from the state mapped shoreline using the San Juan County Public Works building footprint GIS layer. Bulkhead permit trends were analyzed from 1972 (when records start) through 2009; permits were organized by permit type (exemption, substantial shoreline development and code investigation) as well as bulkhead activity type (new and repair/replace).

Armor Impacts to Forage Fish Spawning Habitat: Forage fish spawning habitat and armor were assessed for their relationship to shoreform, and to each other. In addition, known impacts to spawning habitat including direct burial of the egg incubation zone, and impacts to sediment supply and sediment transport were evaluated. The presence or absence of marine riparian vegetation at documented spawning sites, and associated armored spawn sites, was also assessed.

Direct Burial: Burial area of spawning habitat was quantified by the linear shoreline length of impact of armor with a toe elevation between +4 MLLW and + 10 feet Mean Lower Low Water (M.L.L.W.) and a beach slope estimate for each unique shoretype based on shoretype, orientation and fetch characterization conducted using field studies of over 30 sites completed by Coastal Geological Services (CGS 2012 Appendix B. Beach slope characterization for San Juan County shoreforms).

Sediment Supply: Impacts to sediment supply, essential to the formation and long term maintenance of the spawning substrate size range required by surf smelt and Pacific sand lance, were evaluated by the number and length of armoring of feeder bluffs located in drift cells with documented spawning beaches.

Sediment Transport: Impacts to sediment transport were assessed by quantifying armor with a toe elevation below mean sea level in drift cells with documented forage fish spawning habitat, as well as the location of groins in drift cells with documented forage fish spawning habitat.

Sea Level Rise Inundation: Likely future lost area of spawning habitat from rising sea levels was calculated for armored documented spawn sites using the most recent sea level rise inundation polygons for San Juan County (MacLennan and Waggoner 2013), armor toe elevation, armor length, beach slope and known spawning habitat extent (+4 to +10 M.L.L.W.), as applied in the direct burial calculation, but for the area waterward of the armor, instead of landward. Armor toe and length data was derived from the 2009 Inventory of Shoreline Modifications (FSJ 2010), beach slope estimate based on shoretype, orientation and fetch from field studies of over 30 sites conducted by Coastal Geological Services (CGS 2012 Appendix B. Beach slope characterization for San Juan County shoreforms).

Marine Riparian Vegetation: The presence of overhanging marine riparian vegetation was characterized at the shoreform scale for those shoreforms with documented forage fish spawn using existing shoreform scale data (Whitman et al. 2012). Visual assessment of overhanging vegetation conditions was also conducted at the site scale for sites where armor was coincident with documented forage fish spawn habitat.

Results

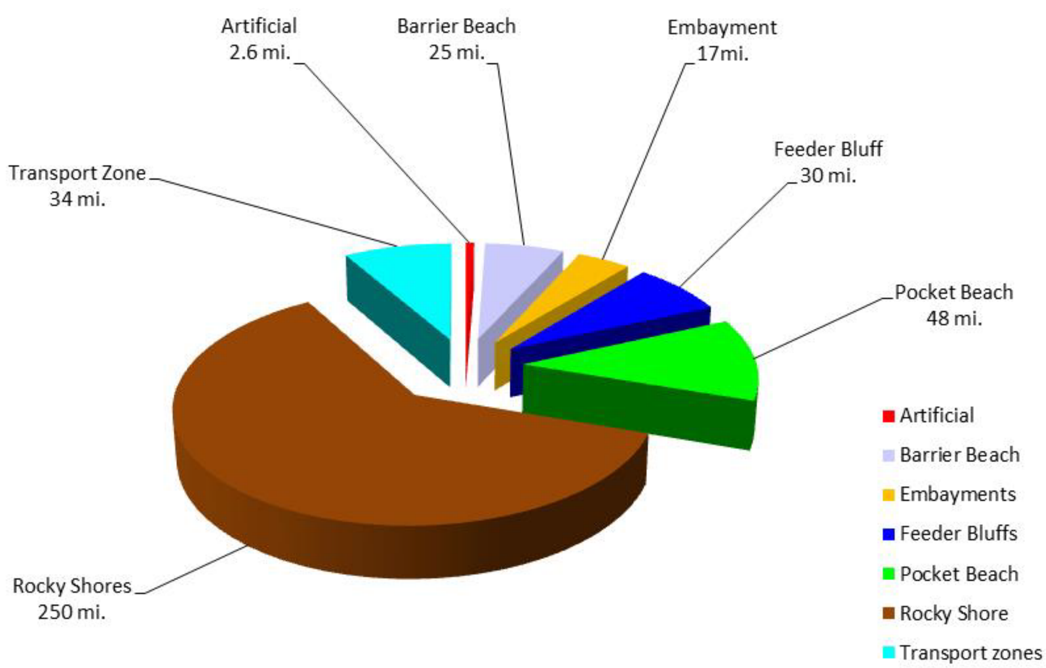
<u>Countywide Shoreline Development Analysis</u>

Nearly 5,000 individual tax parcels are located along San Juan County's 408 miles of marine shoreline. Over half of these parcels are located along rocky or pocket beach geomorphic shoreforms. Approximately one third of parcels in San Juan County are located within drift cells (comprised of feeder bluffs, transport zones and barrier beaches). Embayment estuaries and lagoons comprise a small component of the overall shoreline, with multiple small systems dispersed countywide. San Juan County lacks large river deltas. See Table 1 and Figure 1 for details on County parcel count and length by geomorphic shoreform.

Table 1. San Juan County Shoreline Parcel Distribution by Shoreform

Shoreform	Shoreline Parcels (count)	Shoreform length (miles)
Artificial	27	2.6
Barrier Beach	610	25
Transport zones	474	34
Feeder Bluffs	599	30
Embayments	237	17
Pocket Beach	1,346	48
Rocky Shore	1,563	250
SJC totals:	4,856 parcels	408 miles

Figure 1. San Juan County Shoreline Parcel Distribution by Shoreform



Ownership and Development Status

Based on data from the San Juan County Assessor, including land use codes and building values, 92% of shoreline tax parcels in San Juan County are in private ownership and can be classified as already developed or developable. Parcels classified as conservation or public/educational ownership were removed from this classification. Of the 4,465 shoreline tax parcels in private, developable ownership, 70% (3,144) have already been developed with a primary structure and 30% (1,321) of the private, developable, shoreline parcels have no primary structure. See Table 2, Figure 2, and Map Book 1 for shoreform and spatial distribution of shoreline parcel ownership and development.

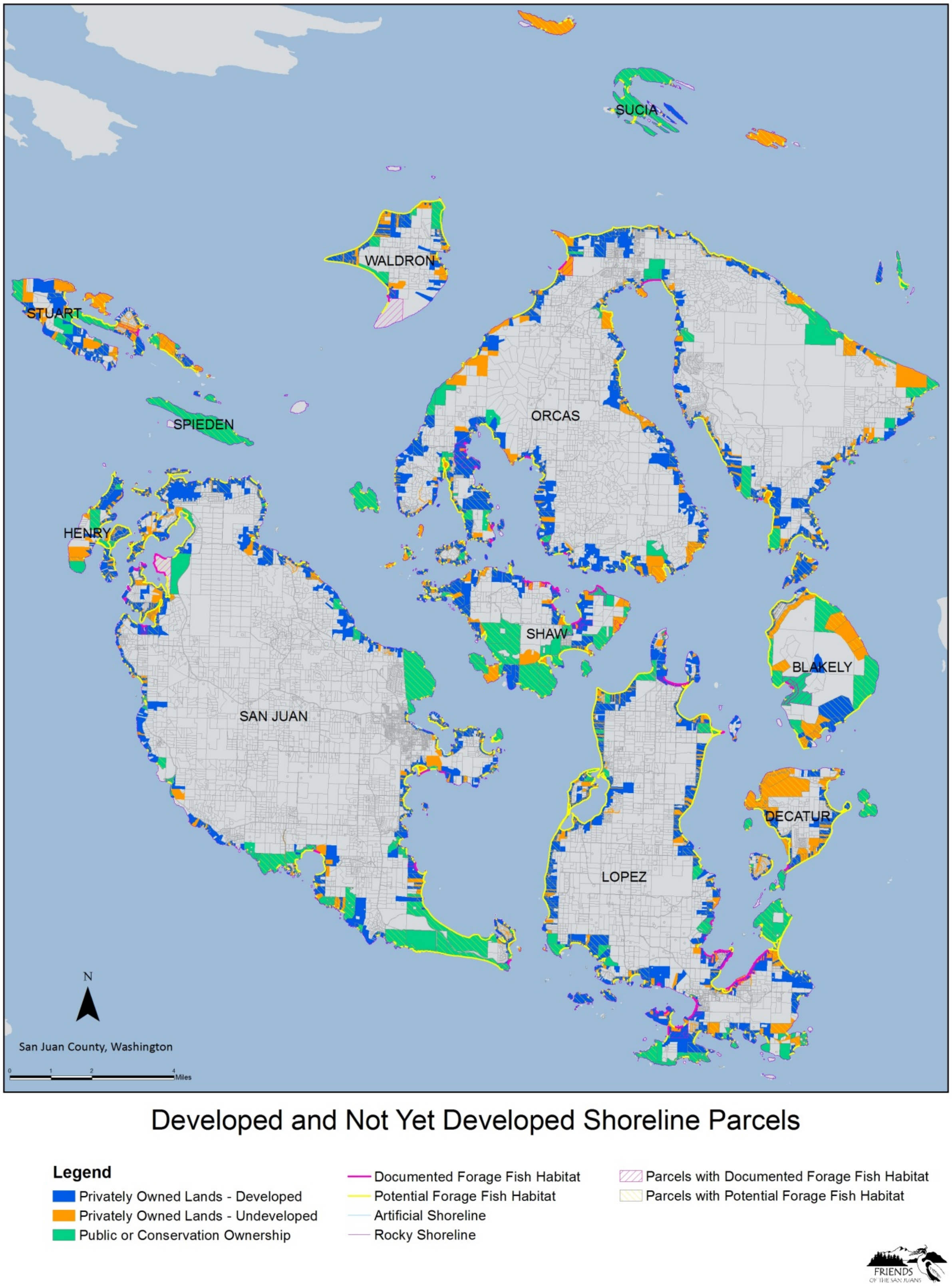
Table 2. San Juan County Shoreline Private Parcel Ownership and Development Status

Shoreform	Private, developed*	Private, not yet developed**
Artificial	14	12
Barrier Beach	403	151
Transport zones	340	122
Feeder Bluffs	433	143
Embayments	140	70
Pocket Beach	840	376
Rocky Shore	974	447
SJC totals:	3,144 (70%)	1,321 (30%)

**Developed parcels defined using San Juan County Assessor use codes and building value.*

***Undeveloped (developable) shoreline parcels have conservation, public and education ownerships removed.*

Figure 2. San Juan County Shoreline Parcel Ownership and Development Status Map



Protected Shoreline Parcels

Just 5% (245) of shoreline tax parcels in San Juan County were classified as conservation ownership, defined for this project as San Juan County Land Bank ownership or easement, San Juan Islands Preservation Trust ownership or easement or current enrollment in the Open Open Space tax incentive program. Conservation parcels are broadly distributed across geomorphic shoreform types, including: rocky (81 parcels), pocket beach (85 parcels), drift cell systems (60 parcels) and embayments (19 parcels). The remaining 3% (146) of shoreline parcels are in public or education ownership. Some, but not all of these public ownerships have conservation as a primary management objective, such as the National Park Service properties on San Juan Island. See Table 3, Figures 3 and 4, and Map Book 1 for shoreform and spatial details on protected shoreline ownership. It should be noted that while conservation ownership is a very small percentage of overall shoreline ownership, conversation ownership parcels do tend to be larger than average private shoreline parcel size. Significant differences between the San Juan County Assessor mapped shoreline GIS data line and the Washington State shoreline that shoreforms are mapped to, accurate parcel length by geomorphic shoreline relationships are not possible.

Table 3. San Juan County Shoreline Parcel Conservation and Public Ownership

Shoreform	Shoreline Parcels (count)	Conservation*	Public or Educational**
Artificial	27	0	1
Barrier Beach	610	36	20
Transport zones	474	9	3
Feeder Bluffs	599	15	8
Embayments	237	19	8
Pocket Beach	1,346	85	45
Rocky Shore	1,563	81	61
SJC totals:	4,856 parcels	245 (5%)	146 (3%)

** Open Open Space Program, San Juan Preservation Trust or SJC Land Bank easement or ownership.*

*** County, State, Federal or educational ownership.*

Figure 3. San Juan County Shoreline Property Ownership (parcel count)

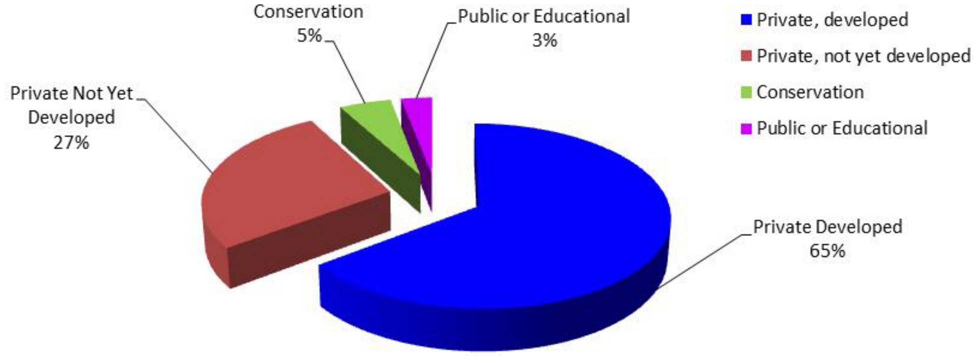
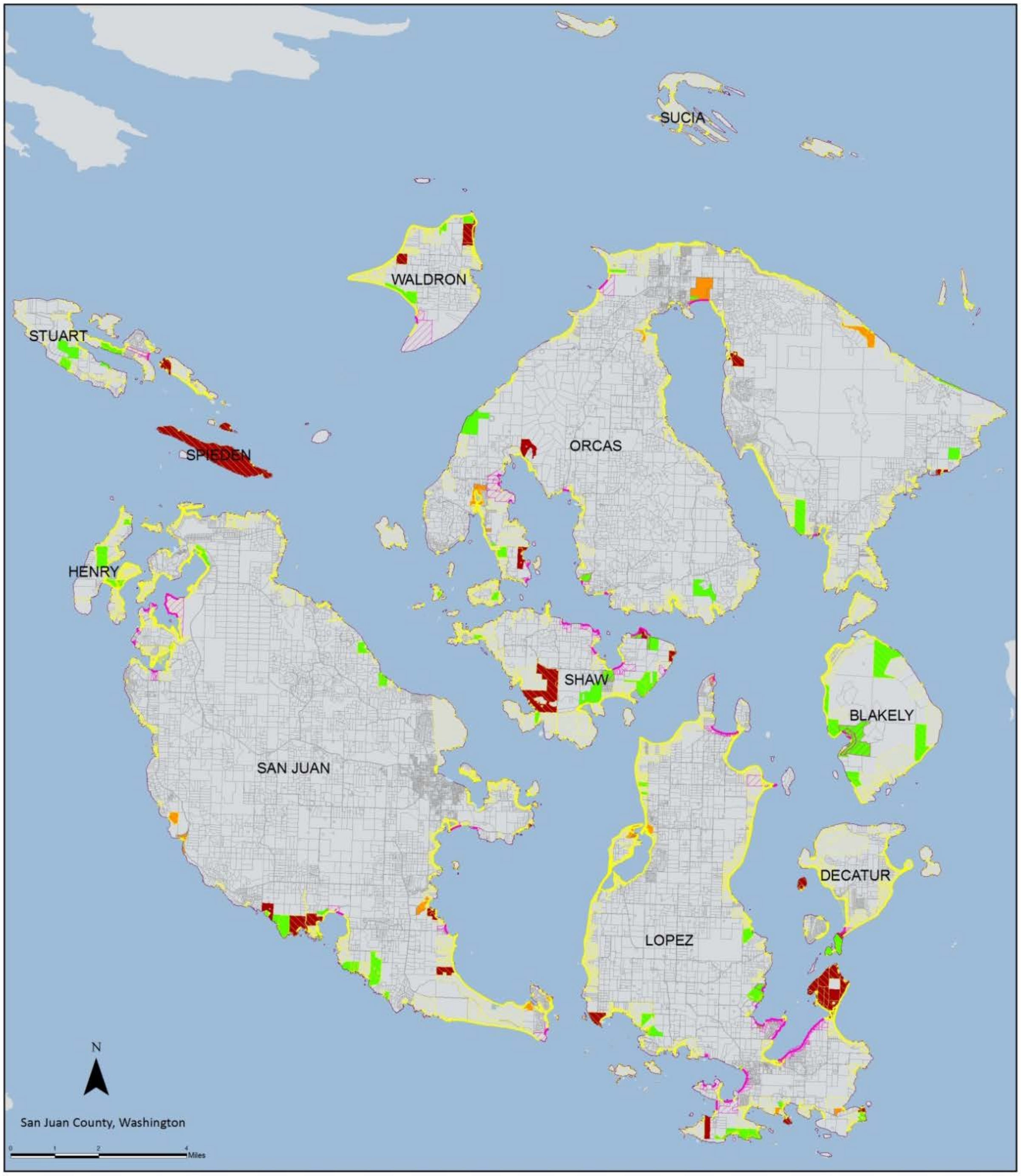


Figure 4. San Juan County Protected Shoreline Parcels Map



San Juan County Protected Shoreline Parcels

Legend

SJC Land Bank Parcel
San Juan Preservation Trust Parcel
SJC Open Open Space Parcel
Documented Forage Fish Habitat
Potential Forage Fish Habitat
Artificial Shoreline
Rocky Shoreline
Parcels with Documented Forage Fish Habitat
Parcels with Potential Forage Fish Habitat

FRIENDS OF THE SAN JUANS

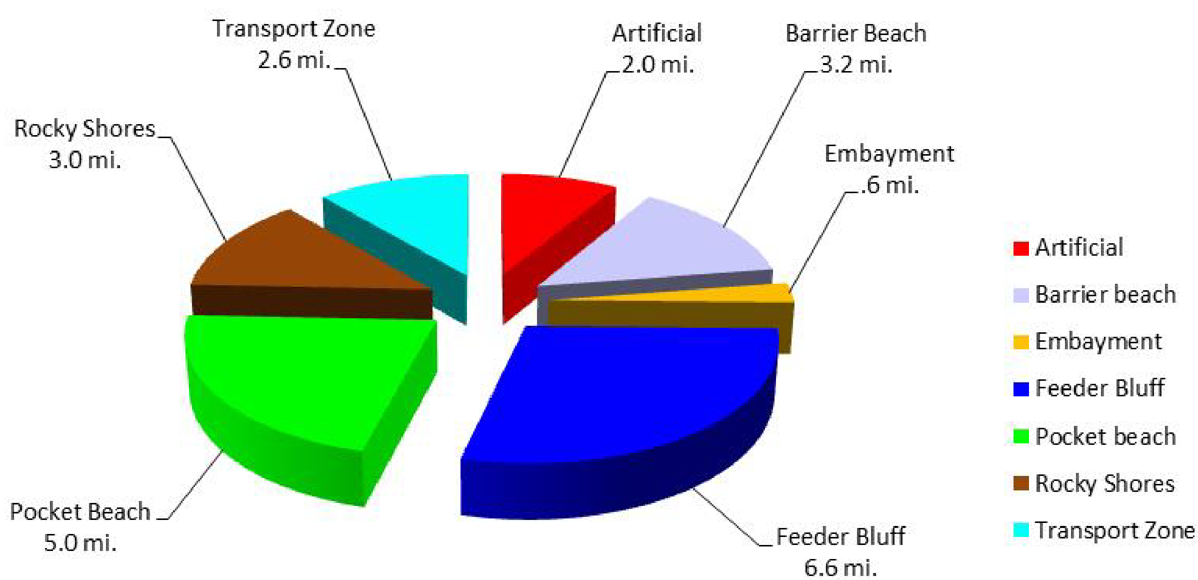
Shoreline Armoring In San Juan County

926 segments of shoreline armoring are mapped in San Juan County, for a total of 23 linear shoreline miles (FSJ 2010). A total of 927 shoreline parcels (18% of total shoreline parcels) have armoring along at least a portion of their length, including 31% of parcels in artificial shoreforms, 11% of parcels in barrier beach shoreforms, 29% of parcels in both transport zones and feeder bluffs, 14% of parcels in embayments and 14% of parcels in rocky shoreforms (FSJ 2010). See Table 4 and Figure 5 for more details. Note: while some armoring does exist along bedrock shores, very small pocket beaches and tombolos with beaches are often mapped as rocky shoreline.

Table 4. San Juan County Shoreline Armor Count and Length by Shoreform

Shoreform	Armor segments (count)	Armor segments length (miles)
Artificial	12	2
Barrier beach	69	3.2
Transport Zone	145	2.6
Feeder Bluff	180	6.6
Embayment	41	0.62
Pocket beach	252	5
Rocky Shores	227	3
County totals	926	23 miles

Figure 5. San Juan County Shoreline Armor Length by Shoreform



Armor and Building Setback

Eighty-eight percent (88%) of shoreline parcels with armoring also have a building on the property (SJC 2013). There is a strong relationship between the building setback (defined in this analysis as the distance between the waterward edge of the building footprint to the mapped shoreline) and the likelihood of shoreline armoring. Forty percent of the shoreline parcels with both buildings and armor have the building footprint closer than 50 feet to the shoreline. Just over thirty-four percent of shoreline parcels with buildings and armor have structures located from 50 to 100 feet from the shoreline. Nearly twenty percent of parcels with buildings and armor have building footprints from 100 to 200 feet from the marine shoreline. Just six percent of shoreline parcels with buildings and armor have building footprints located greater than 200 feet from the marine shoreline.

While these results are to be expected, they also clearly illustrate the strong association between building setback and the presence of shoreline armoring, with 74% of shoreline parcels with both buildings and armor having setbacks of 100 feet or less. The relationships are even more pronounced within certain shoreforms, such as embayments where 90% of parcels with buildings and armor have a setback distance of less than 100 feet, pocket beaches where 78% of parcels with buildings and armor with setbacks less than 100 feet, and barrier beaches where 76% of parcels with building and armor with setback distances of less than 100 feet. While the embayments result likely reflects the relatively small parcel size within embayments as well as earlier time periods of development in the county, the high percentage of armored parcels is still remarkable considering embayments are further protected relative to other areas of the county from wave energies by their very nature. Barrier beach shoreforms is another interesting place with high armoring with close buildings, as the very definition of barrier beaches is that they are accretion shoreforms, places where shoreline armoring should be geologically unnecessary. See Table 5, Figures 6 and 7 and Map Book 2 for more information on armored developed parcels and building setback.

Table 5. San Juan County Developed Parcels with Armor and Building Setback

Shoreform	Parcels w/ armor and building total	Building footprint <50 ft.	Building Footprint 50-100 ft.	Building footprint 100-200 ft.	Building footprint >200 ft.
Artificial	5	4	1	0	0
Barrier beach	71	23	31	11	6
Transport Zone	104	50	30	16	8
Feeder Bluff	232	54	92	68	18
Embayment	42	28	10	1	3
Pocket beach	310	135	108	54	13
Rocky Shores	53	29	10	16	8
County totals	817	323 (40%)	282 (34%)	161 (20%)	51 (6%)

Figure 6. Developed Parcels with Armor and Building Setback

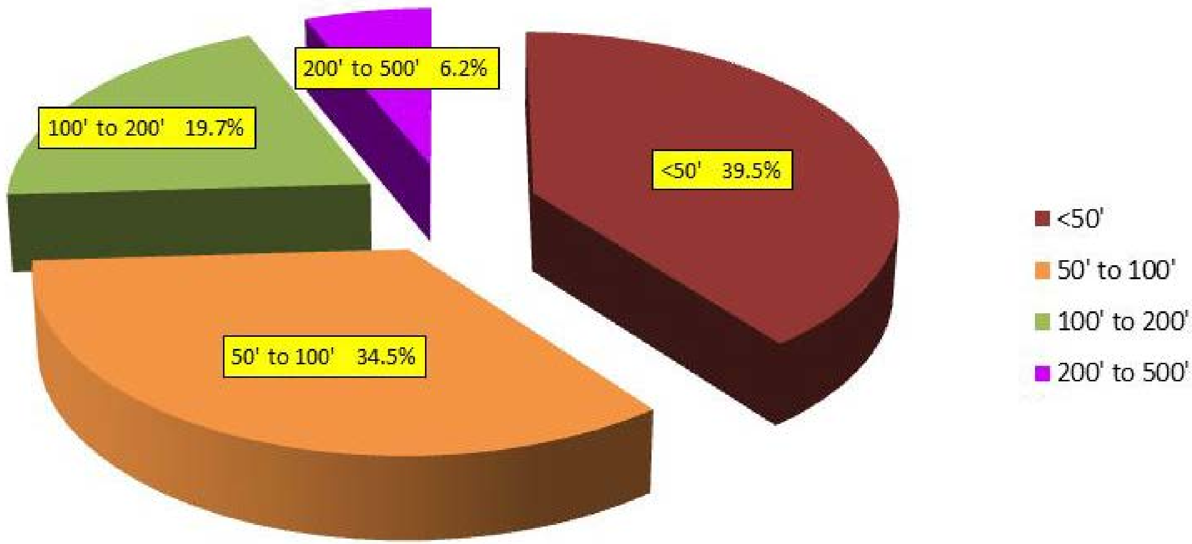
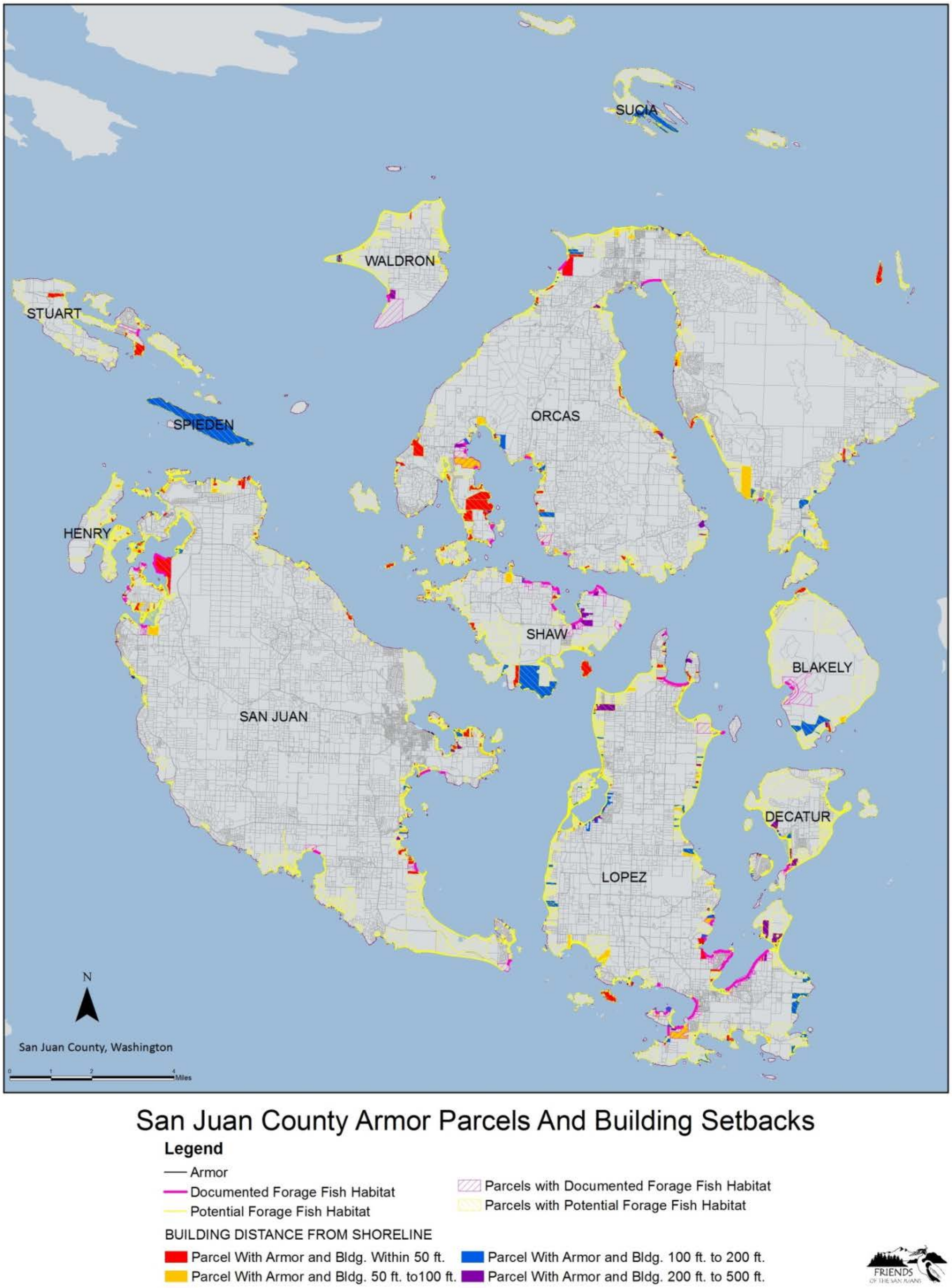


Figure 7. San Juan County Armored Shoreline Parcels and Building Setback Map



San Juan County Bulkhead Permit Trends

The Community Development and Planning Department of San Juan County maintains databases of all permit activity. Shoreline permits for new bulkheads, bulkhead repairs and replacements and code investigations related to bulkheads were analyzed for this project by both permit and project type. Data was organized into two time periods (1972-1992 and 1992-2009) to reflect adoption of specific forage fish spawning habitat protection language in the County's 1992 Critical Areas Ordinance and Shoreline Master Programs. Results shown in Figure 8 and Table 6 indicate that the annual rate of residential exemptions for the installation of new bulkheads have increased slightly in the later time period and that the rate of repair/replace exemptions issued have more than doubled. Rates of shoreline substantial development permits for new armor installations and repair/replacements have also increased and the number of code investigations related to bulkhead development have greatly increased. The results demonstrate that current regulatory protection policies are not reducing rates of armoring along San Juan County's shores.

Figure 8. San Juan County Bulkhead Permit Trends

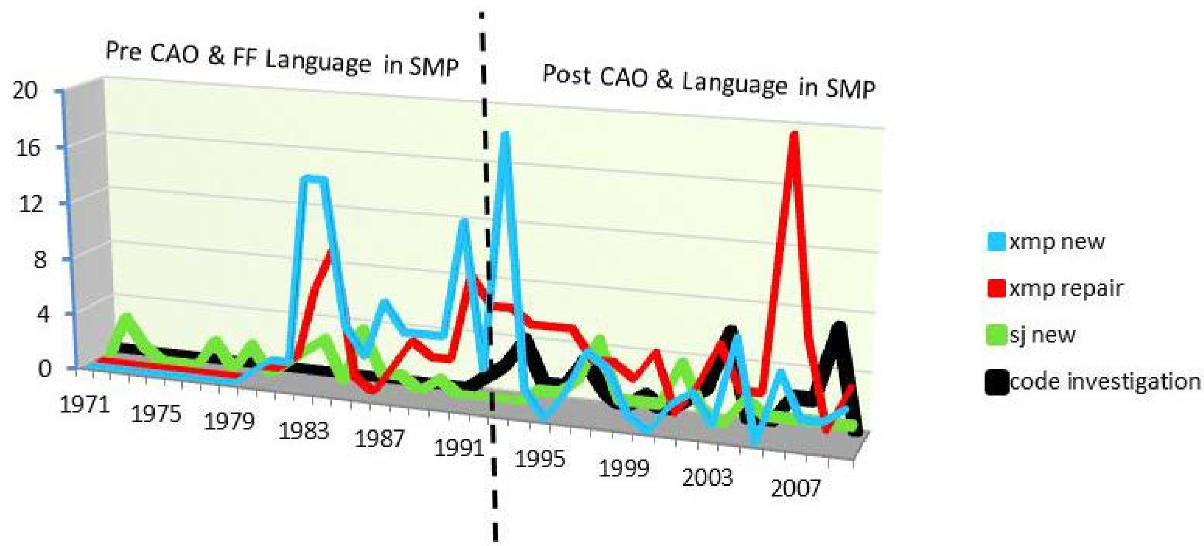


Table 6. San Juan County Bulkhead Permit Trends (1972-2009)

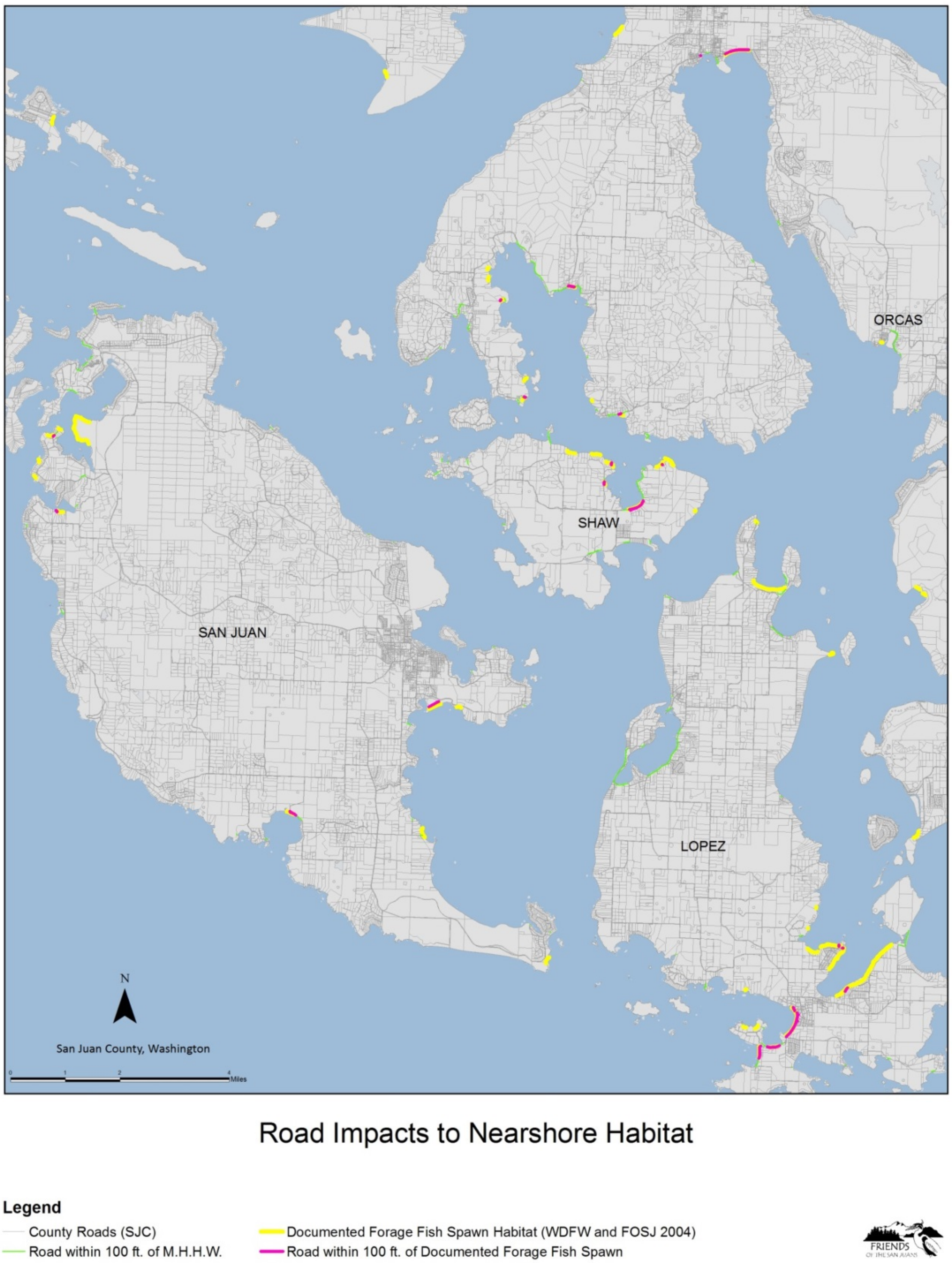
Permit Type	1972-1992 Count	1972-1992 Annual Rate	1993-2009 Count	1993-2009 Annual Rate
Exemption-new bulkhead	81	3.6 per yr.	58	3.4 per yr.
Exemption- repair/replace	50	2.3 per yr.	89	5.23 per yr.
Substantial development- new bulkhead	21	0.95 per yr.	24	1.4 per yr.
Code Investigations	3	<1 per yr.	31	1.8 per yr.
Totals:	155	7 per yr.	202	12 per yr.

1972-1992 First Shoreline Master Program policies and regulations in place.
1992 New CAO and SMP adopted in San Juan County, specific language added to protect forage fish spawning habitats.
Data source: SJC Community Development and Planning Permit Databases (December 2010).

Shoreline Armoring and Public Roads

Public infrastructure in the marine nearshore currently provides a significant impact, and future restoration opportunity, for San Juan County. Over 8 miles of county roads are located along beaches (within 100 ft. of M.H.H.W.) and most of these are armored. Half of these shoreline roads are in four general locations: West Sound (Orcas), Blind Bay (Shaw), Fisherman Bay (Lopez) and Barlow Bay/MacKaye Harbor (Lopez). East Sound and False Bay also have significant stretches of backshore roads. All of these sites with the exception of Fisherman Bay are areas with documented sand lance and/or surf smelt spawn. Most of these roads have significant rock armor and rip rap along their lengths, in many cases this shore protection is old and outdated, and fallen rocks well down on the beach face are common. In addition, seven county-owned tax parcels have bulkheads (5 Public Works and 2 Land Bank parcels). See Figure 9 for detailed locations of roads and habitat.

Figure 9. San Juan County Nearshore Roads Map



Forage Fish Spawning Habitat

Forage Fish Spawning Habitat and Geomorphic Shoreform

To date, just under ten miles of surf smelt and/or Pacific sand lance spawning beaches have been documented in San Juan County. Sporadic spawning habitat assessment surveys were conducted by the Washington Department of Fish and Wildlife beginning in the late 1980's and a concentrated survey effort was completed by Friends of the San Juans, in partnership with WDFW, Friday Harbor Marine Labs and the San Juan County Marine Resources Committee from 2001-2003. Potential spawning habitat was assessed through a combination of aerial photo interpretation and field-based analysis of suitable spawning substrate. Over 85 miles of potential spawning habitat is documented in San Juan County.

Additional spawning is likely, as many sites remain to be sampled or have been sampled just once or twice and eggs incubate on the beach from just 2 to 4 weeks, depending on the season. In addition, there are nine sites in the county where just one egg was found in field surveys, missing the required protocol of two eggs to be included on the documented spawn maps. Two-thirds of spawn in San Juan County occurs within drift cells systems, with fairly equal distribution across feeder bluffs, transport zones and barrier beaches. One third of spawn in San Juan County occurs on pocket beaches and beaches mapped as rocky, which include very small pocket beaches as well as beaches associated with tombolos. Just a few hundred feet of spawn is documented along an artificial shoreform (just west of the Bayhead Marina along the jetty). See Table 7 and Figures 10 and 11 for more information.

Table 7. San Juan County Shoreforms and Documented Forage Fish Spawning Habitat

Shoreform	Shoreforms with Spawn Count	Spawn length by shoreform
Artificial	1	286 ft.
Barrier beach	21	2.1 miles
Transport Zone	31	1.8 miles
Feeder Bluff	41	2.1 miles
Embayment	0	0
Pocket beach	42	3.3 miles
Rocky Shores	4	0.4 miles
County totals	140 shoreforms	9.7 miles

Figure 10. Forage Fish Spawn Habitat by Shoreform

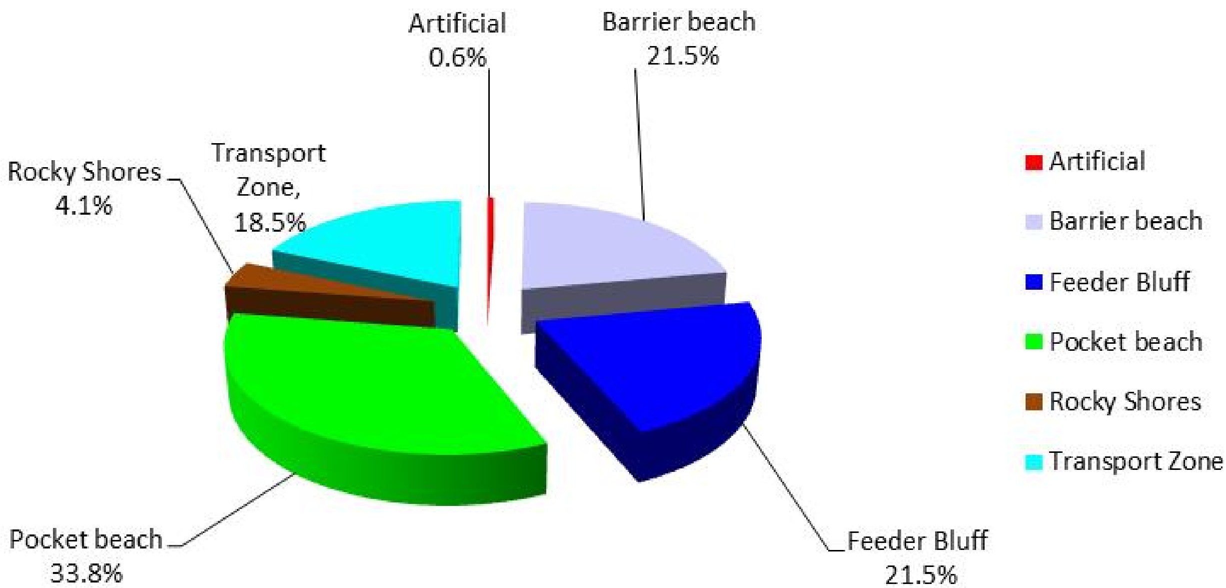
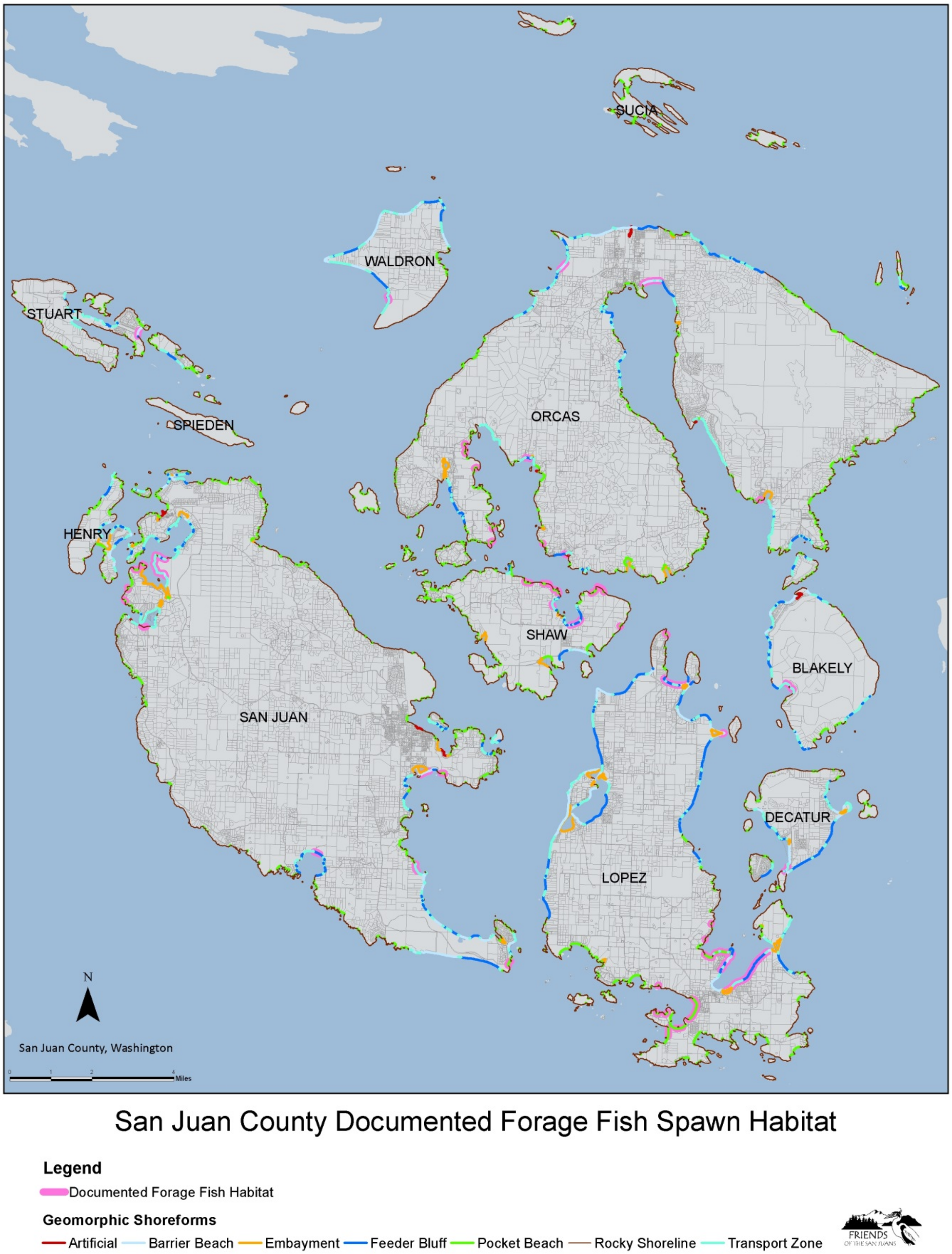


Figure 11. Forage Fish Spawn Habitat and Geomorphic Shoreform Map



Shoreline Tax Parcels and Forage Fish Spawn

Countywide, 283 shoreline tax parcels have documented spawn along some portion of their length and 3,126 shoreline parcels have potential spawn habitat (defined as not documented spawn and not artificial or rocky shoreform).

Conservation ownership: Just over one mile of documented forage fish spawning beaches are currently protected by conservation easement or ownership including 19 tax parcels for a total of 5,738 feet. This includes 3 parcels in the Open Open Space Program (2,085 ft.), 12 parcels in Preservation Trust easement or ownership (3,226 ft.), and 4 parcels in San Juan County Land Bank easement or ownership (1,645ft.). Some overlap exists between Open Open Space and Preservation Trust Easement parcels. Protected documented spawn parcels are located on Orcas (5 parcels, 1,719 ft.), Shaw (4 parcels 1,319 ft.), Lopez (4 parcels, 887 ft.), Waldron (1 parcel, 225 ft.) and Blakely/Decatur Islands (5 parcels, 1,179 ft.).

11% of documented spawn habitat in San Juan County is currently in protected, or conservation ownership. While this does not mean that protection of forage fish habitat and habitat forming processes are specifically called out in the easement or management plans for the site (the San Juan Initiative found just a small portion of easements called out forage fish habitat), it does offer assurance that new structures will not be built on the shoreline and that marine riparian vegetation will be retained (San Juan Initiative 2008).

Public ownership: Approximately 1.5 miles of documented forage fish spawn is currently in public or educational ownership, including a significant holding by the National Park Service at English Camp. Documented spawn habitat in public and educational ownership occurs on 12 tax parcels (8,334 ft.), including 5 pocket beaches, 4 barrier beaches, 2 feeder bluffs and 1 transport zone. Nearly 60% of documented spawn in public/educational ownership is located in British Camp National Historical Park on San Juan Island, with remaining public properties with documented spawn located elsewhere on San Juan as well as on Lopez and Waldron Islands. A broad range of management policies and plans apply to shoreline parcels in public ownership, for example shoreline parks may include extensive infrastructure such as boat landings, ramps and docks. However, public ownership does indicate at least the potential for implementation of long-term protection, restoration, stewardship or educational actions aimed to improve conditions for beach spawning forage fish. See Figure 4 and Map Book 1 for locations of protected shoreline parcels and forage fish habitat.

Documented Forage Fish Spawn Habitat and Shoreline Development

Developed shoreline parcels were defined as those parcels not in conservation, public or educational ownership, with building values greater than $10,000 and no undeveloped land use code assignment in the San Juan County Assessor's database. As such, developed in this instance is related to the presence of a primary structure such as a residence on the shoreline tax parcel, and not the presence or absence of modifications along the shoreline. 162 shoreline tax parcels that have documented spawn along at all or a portion of their shoreline portion met this definition of developed. Developed shoreline parcels with documented forage fish spawn occur on 66 pocket beaches, 44 feeder bluffs, 29 transport zones, 20 barrier beaches, and 3 rocky shores. Developed parcels with documented forage fish spawn are good sites for targeted shoreline stewardship education, focusing on reducing demand for armoring and the retention of marine riparian vegetation. Intact riparian areas and beaches are also good candidates for long-term protection through conservation easements or the Open Open Space program.

Undeveloped shoreline parcels, for the purposes of this project, are those that are likely to be developed. This definition includes parcels assigned one of the two San Juan County Assessor land use codes for undeveloped properties (codes 1800 and 9100) as well as an assessed building value of less than $10,000. In addition, properties currently in conservation, public or educational ownership have been removed from the analysis, providing a more accurate assessment of remaining build-out potential along forage fish spawning beaches.

58 parcels with documented forage fish spawn habitat met our criteria of undeveloped, but likely to be developed in the future, including parcels on 33 pocket beaches, 10 transport zones, 9 feeder bluffs, 4 barrier beaches and 2 rocky shores. These parcels are potential acquisition sites, as well as excellent places to focus shoreline stewardship efforts, including landowner and developer education. These places are also important areas for protection under existing Critical Areas Ordinance and Shoreline Master Program regulations. This combination of voluntary and regulatory protection should, for example, ensure that new development is appropriately sited to ensure armoring is not needed or desired in the future and every effort should be made to retain marine riparian vegetation. See Table 8 for details.

Table 8. Forage Fish Spawn Habitat, Ownership and Development Status

Parcels with documented spawn	Conservation ownership*	Public or Educational ownership	Private, Developed**	Private, undeveloped***
Barrier beach	3	4	20	4
Transport zone	6	1	29	10
Feeder bluff	0	2	44	9
Embayment	0	0	0	0
Pocket beach	8	5	66	33
Rocky	2	0	3	2
	19 parcels (8%)	12 parcels (5%)	162 parcels (64%)	58 parcels (23%)

Forage Fish Spawning Habitat and Shoreline Armor

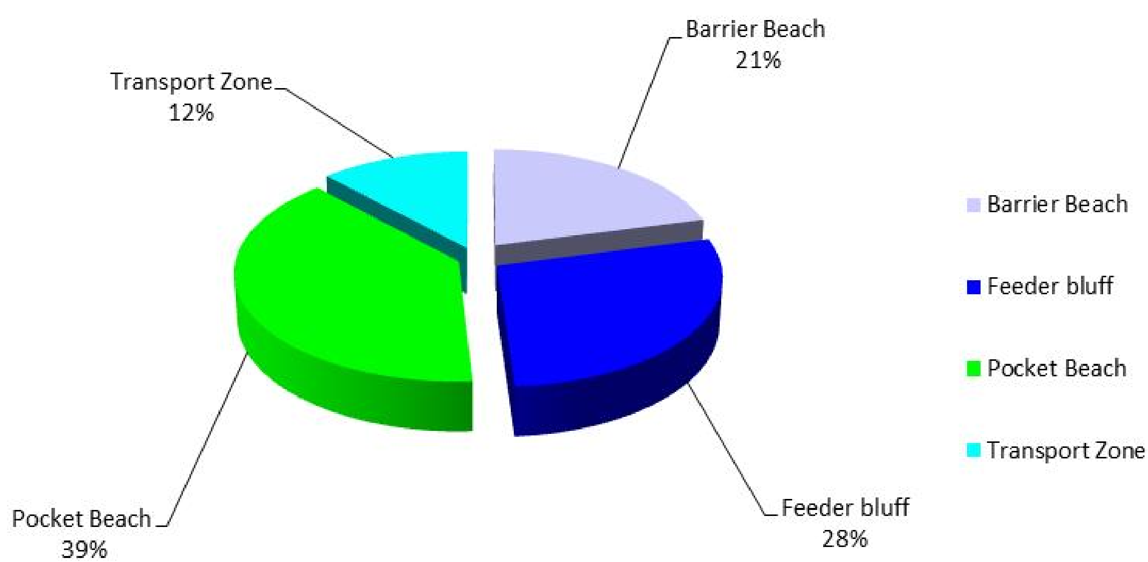
Sixty-five shoreforms in San Juan County have armor coincident with documented spawn habitat along 1.5 linear miles of shoreline. The majority of shoreline armoring at documented forage fish spawning beaches occurs on pockets beaches (39%) and feeder bluffs (28%). See Table 9 and Figure 12 for details of armored forage fish habitat by shoreform. Armored documented spawn beaches are most common on Lopez, followed by Orcas, Shaw and San Juan Islands as well as small sections of armored spawn on Blakely and Waldron Islands. In addition to noting coincidence of armor with known spawning locations, multiple specific impacts of armor to forage fish spawning beaches were evaluated, including direct burial, impacts to sediment supply and impacts to sediment transport.

Table 9. Documented Forage Fish Spawning and Shoreline Armor

Shoreforms with armored doc. spawn	Shoreforms count	Armor on Spawn length (%*)
Artificial	0	0
Barrier Beach	8	1753 ft. (21%)
Transport Zone	12	953 ft. (12%)
Feeder bluff	22	2259 ft. (28%)
Embayment	0	0
Pocket Beach	23	3183 ft. (39%)
Rocky Shores	0	0
Totals:	65	1.54 miles

% = of armored spawn sites

Figure 12. Armored Forage Fish Spawn by Shoreform



Armor and Spawn-Direct Burial

Surf smelt and Pacific sand lance are obligate intertidal spawners, requiring suitable substrate on the upper elevation portion of beaches to successfully incubate and hatch their eggs. The preferred spawning range of the surf smelt is 7 to 9 feet M.L.L.W., roughly at and above mean higher high water in San Juan County and a small proportion of eggs can be located even higher up the beach.

On low profile beach types such as mud flats, the presence of armoring in the tidal elevation range of spawn can result in significant and permanent loss of spawning substrate through direct burial. While the overall area of impact may be less when quantified numerically at a steeper beach face site, as the area of suitable spawn area is also typically narrower at these types of sites, the loss of suitable spawning habitat may be just as severe.

The area of spawning habitat currently lost as a result of direct burial by shoreline armoring in San Juan County was quantified using three data sets, toe elevation of armor between plus 4 MLLW and plus 10 MLLW, mean beach slope, and length of armor coincident with documented spawn. Data source for the armor toe and armor length data was the Shoreline Modification Inventory (FSJ 2010), and reflects field conditions as surveyed in 2009. Mean slope data was derived for this project by Coastal Geologic Services (see Appendix B). Beach slope characterization was completed by CGS to provide average beach widths across geomorphic shoretypes. Slopes were further stratified by orientation (N and S quadrant) and fetch (< 5 miles or > 5 miles fetch). Sites used for the beach slope characterization included 15 feeder bluffs, 13 transport zones, 13 accretion shoreforms and 15 pocket beaches. Feeder bluffs were selected from drift cells without highly impacted sediment sources. Beach slope data for these sites was derived from a combination of field surveys, existing survey data and LIDAR data.

The following equation was used to quantify burial area: ((10 - [CalcTOEonSpawn]) * 100) / [MeanSlope]) * [SpwnARMORoverlap]

Where, the calculated toe on spawn equals armor on documented spawn sites with a toe elevation between + 4 and + 10 MLLW; Mean slope characterization adopted from CGS (2012) based on shoretype, orientation and fetch and spawn armor overlap equals the length in feet of armor coincident with documented spawn.

Sixty-five shoreforms in San Juan County have armor located coincident with documented spawn habitat, along 1.5 linear miles. When mean beach slope data is applied with armor length to calculate burial area, approximately 11 acres (479,703 square feet) of documented spawning habitat is currently buried by shoreline armoring, representing 13% of the 85 acres of total known spawning area in the county. As visible in Figure 13, direct burial impacts are greatest at pocket beaches (4 acres), followed by feeder bluffs (2.6 acres), barrier beaches (2 acres) and transport zones (1.5 acres).   Burial of documented spawn beaches is widespread geographically, with the most sites on Lopez, followed by Orcas, Shaw and San Juan Islands as well as small sections of armored spawn on Blakely and Waldron Island. Figure 14 provides a map of areas impacted by direct burial of forage fish spawn habitat.

Figure 13. Direct Burial of Forage Fish Spawn by Shoreline Armor

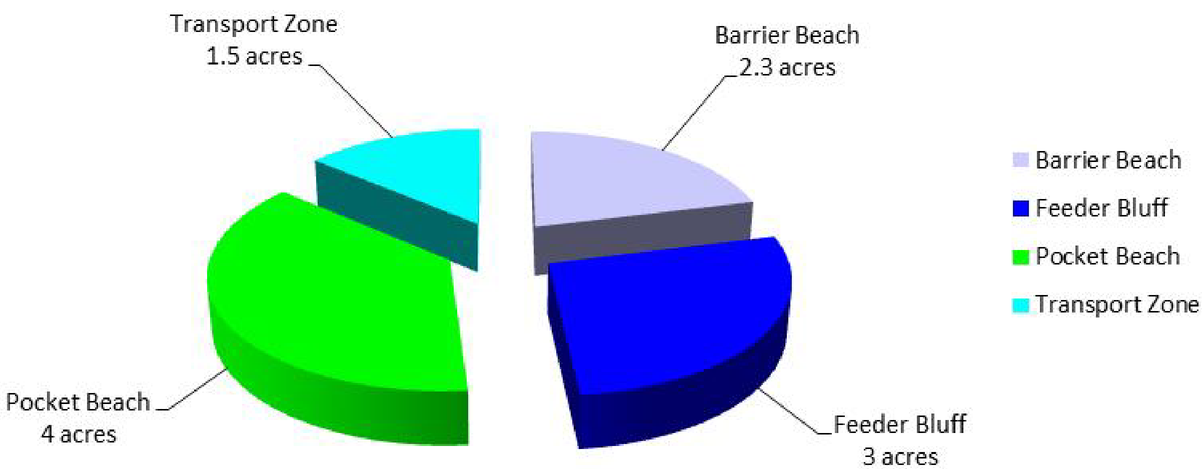
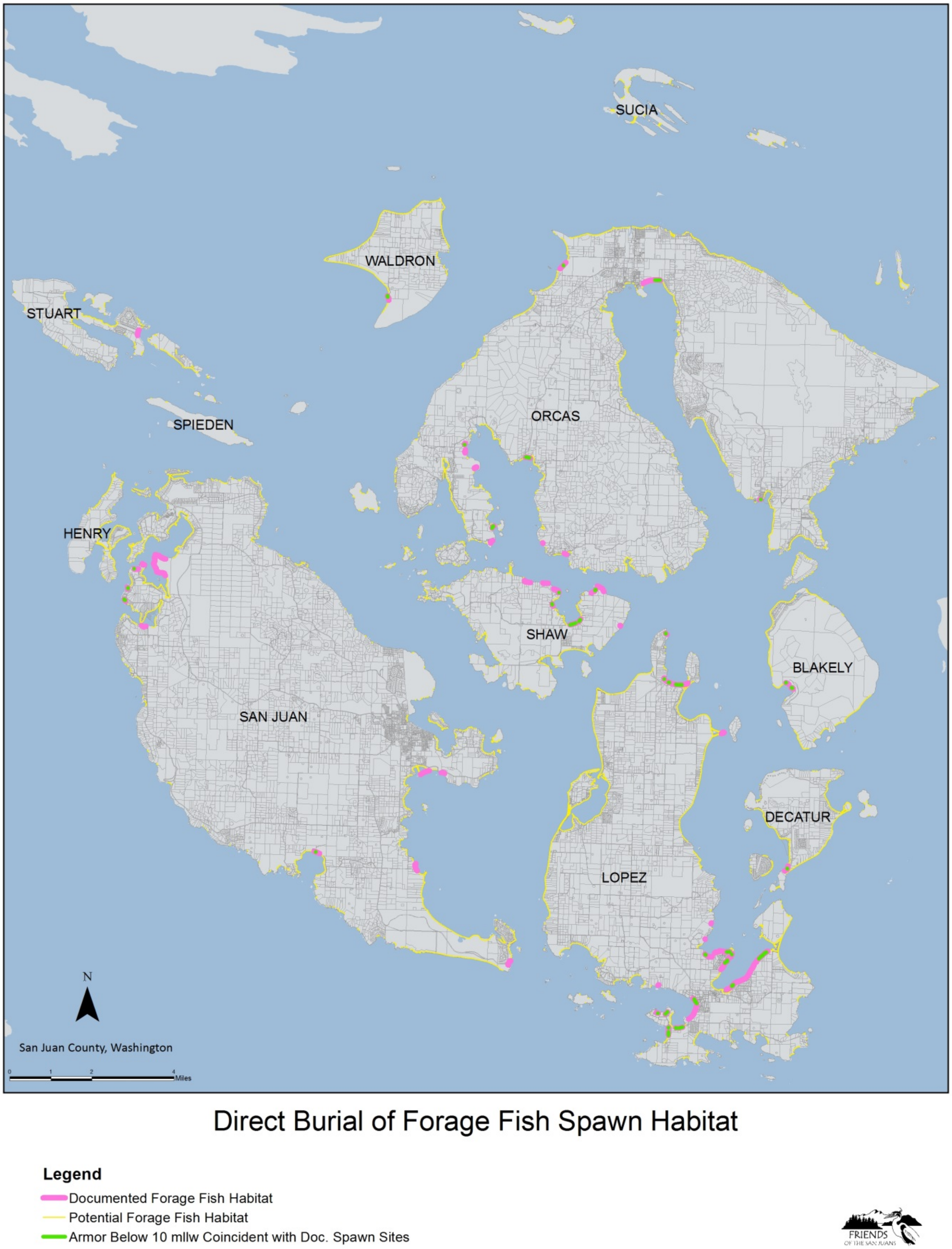


Figure 14. Armor Impacts to Forage Fish Spawn Habitat- Direct Burial Map



Armor and Spawn – Impacts to Sediment Supply

Erosion from bluffs provide over 90% of the beach sediment supply in Puget Sound and bluff sediment is an even larger percentage in San Juan County, which lacks major rivers to transport sediment from inland upland sources. Formation and maintenance of forage fish spawning beaches, with the fine sediment size range required to support beach spawning species such as surf smelt and Pacific sand lance, depends on long-term protection and restoration of coastal sediment processes. Armoring of feeder bluffs, the primary sediment supply source, is a major concern for the long-term maintenance of suitable spawning substrate. This is especially important in drift cells with documented forage fish spawn but county-wide protection of sediment processes in all drift cells is a critical management imperative, to ensure protection of other substrate-dependent functions and values such as shellfish and eelgrass. In addition, documentation of new spawning sites continues to occur in San Juan County and throughout the region.

There are 126 mapped drift cells in San Juan County. Twenty-six of these drift cells have documented forage fish spawn within them. Of those 26 drift cells with documented spawn, 23 (88%) also have armored feeder bluffs and likely impacts to sediment supply. Sixty-four individual feeder bluffs in drift cells with documented forage fish spawning habitat have current armoring. Countywide, there are 169 armored feeder bluffs, for 4.4 miles of shoreline. Roughly one-third of these armored feeder bluffs (1.4 miles) are located within drift cells with documented spawn. Fifty-seven drift cells have armored feeder bluffs, disrupting sediment supply to potential forage fish spawning habitat, or areas where spawn has not yet been documented. Figure 15 and Map Book 3 identifies the areas in San Juan County most impacted by sediment supply loss due to armoring.

To ensure adequate sediment supply to maintain forage fish spawning substrate at known spawning sites into the future, restoration of armored feeder bluffs in drift cells with documented spawn is a priority. Protection of intact feeder bluffs within drift cells with documented forage fish spawning habitat should also be a top management strategy.

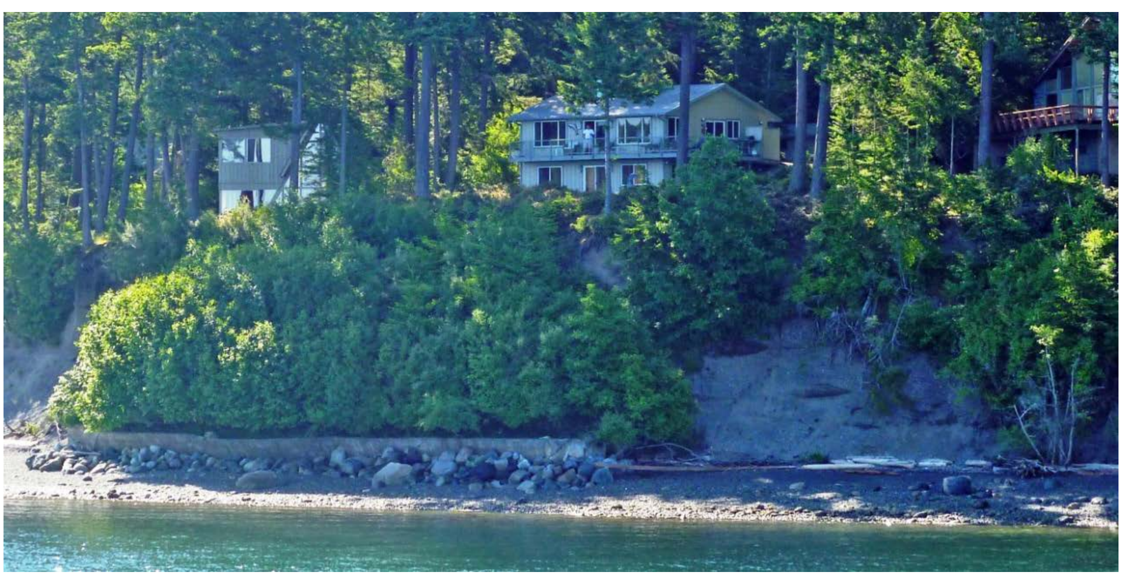
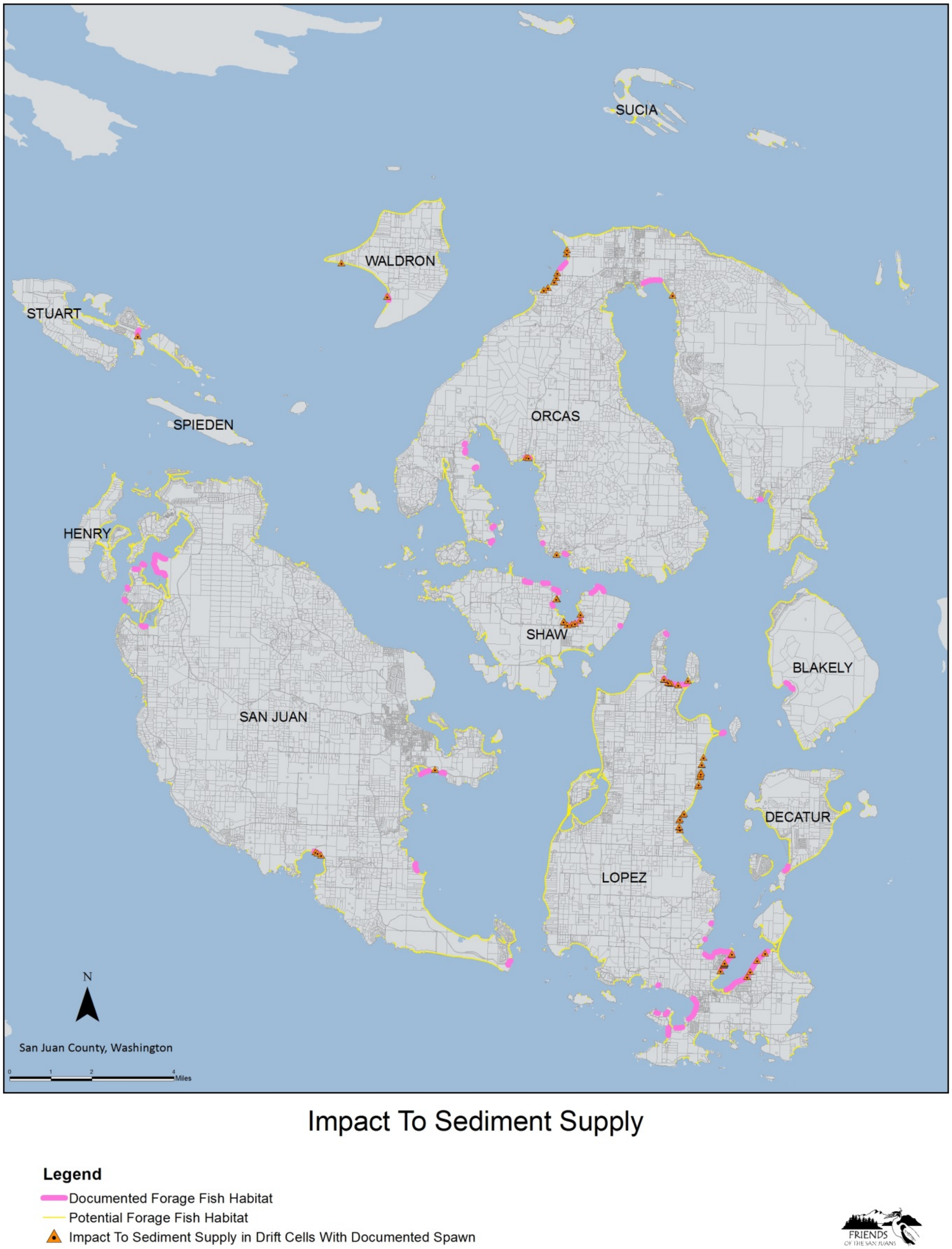


Figure 15. Armor Impacts to Known Forage Fish Habitat- Sediment Supply Map



Armor Impact to Forage Fish Spawn- Impacts to Sediment Transfer

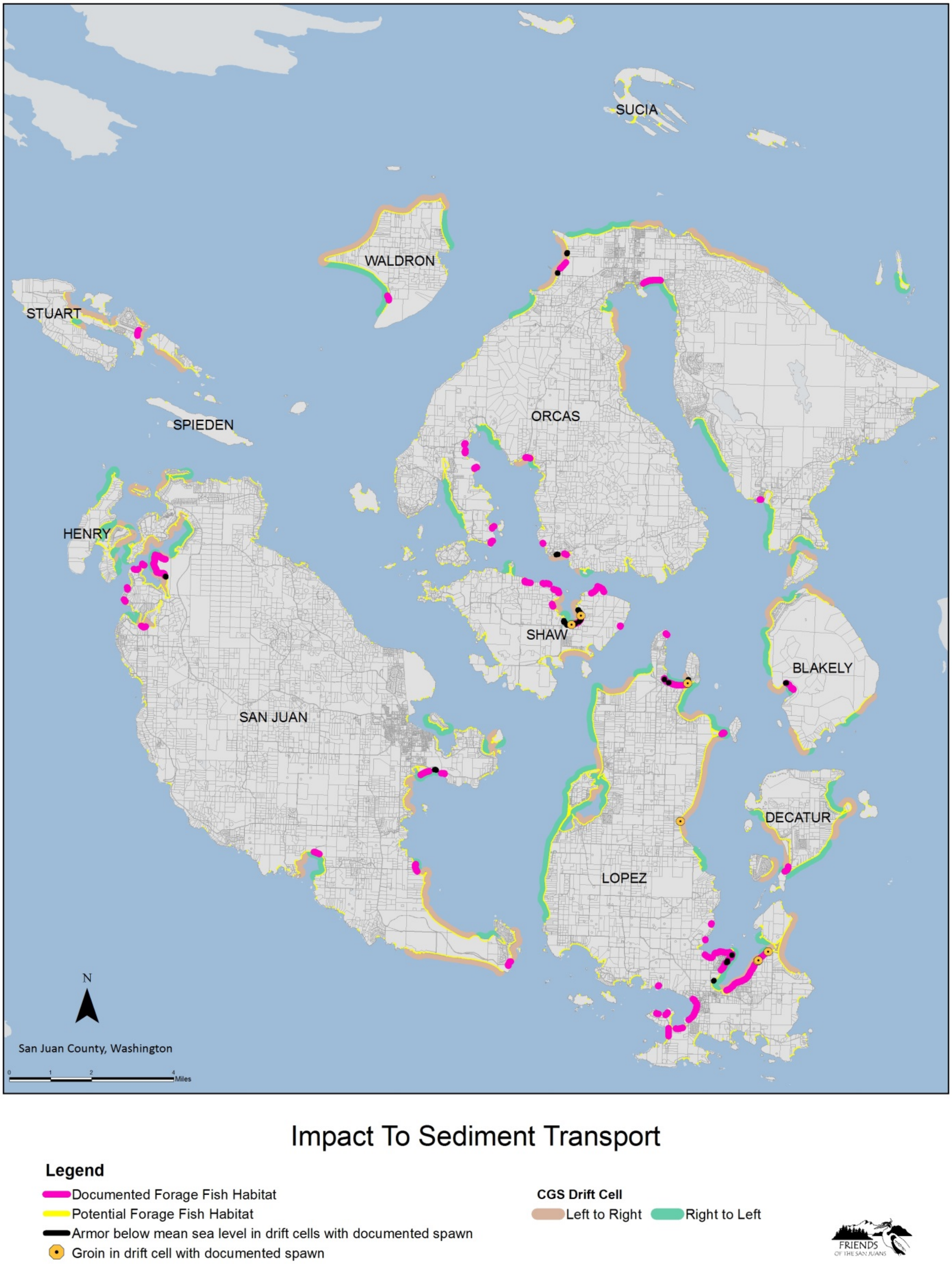
In addition to impacts to sediment supply, shoreline armoring can also disrupt sediment transport processes. Impacts to littoral drift were evaluated by identification of armoring with toe elevation at mean sea level and below. Mean sea level has been determined for multiple San Juan County sites by NOAA; the value of 4.5 feet M.L.L.W. (Friday Harbor NOAA station) was used in this countywide analysis. The severity of the impact to sediment transport processes also depends on shoreform, and location relative to documented or potential spawning habitat, with the largest impacts to sediment transport occurring when armoring with a toe elevation below mean sea level is located on feeder bluffs or transport zones updrift of documented forage fish spawning beaches.

Just under one total linear mile of armor with a toe elevation below mean sea level was documented in San Juan County drift cells with documented forage fish spawning beaches, including:

- 6 barrier beaches (20% of impact by shoreform count and 22% of overall impact length),
- 7 transport zones (25% of impact by shoreform count and 55% of impact by shoreform count and 18% of overall impact length) and
- 16 feeder bluffs (55% of impact by shoreform count and 60% of overall impact length).

An additional known impact to sediment transport-groins-was also quantified for drift cells with documented forage fish spawn. A total of seven groins are located in drift cells with documented forage fish spawning beaches, including 5 feeder bluffs and 2 barrier beaches. See Figure 16 and Map Book 3 for detailed location information.

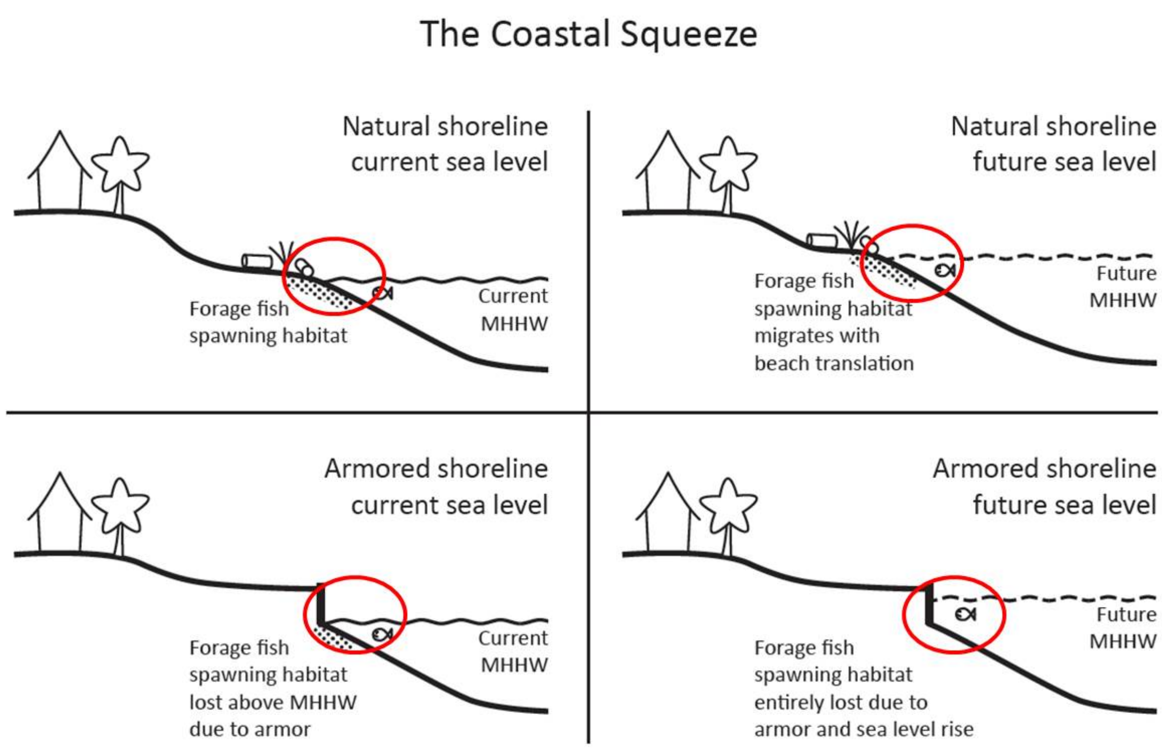
Figure 16. Armor Impacts to Known Forage Fish Spawn- Sediment Transport Map



Armor Impact to Forage Fish Spawn- Inundation by Rising Sea Levels

Located on the upper intertidal portions of beaches, forage fish spawning habitat is vulnerable to the impacts of sea level rise, especially at armored sites where hardening presents a barrier to natural shoreline translation (Krueger et al. 2009). This situation, commonly referred to as the "coastal squeeze", is illustrated in Figure 17. The Coastal Squeeze and Forage Fish Habitat (Coastal Geologic Services 2013). In addition to narrowing of the upper beach as a result of rising water levels against a static structure the presence of armoring will also exacerbate the coarsening of upper intertidal sediment grain-sizes by wave reflectance off the armoring structures (Johannessen and MacLennan (2007), acting in concert to degrade forage fish spawning habitat substrate.

Figure 17. The Coastal Squeeze and Forage Fish Spawning Habitat



Coastal Geologic Services 2013

Using the most current information on rising sea levels for the marine shorelines of San Juan County (MacLennan and Waggoner 2013), coupled with data on armor toe elevation and length (Friends of the San Juans 2010) and beach slope (Coastal Geologic Services 2012) estimates of habitat area inundated by sea levels was calculated for armored documented forage fish spawning sites. Methods were the same as used to calculate direct burial, but applied to the area within the spawning habitat zone waterward of armor that intersected inundation polygons, instead of the area landward of the armor at known spawning sites. Results indicate that 3 acres

(123,703 square feet) of spawning habitat will be impacted at armored sites. See Figure 14 for detailed location information on armored forage fish sites vulnerable to inundation.

Forage Fish Habitat and Marine Riparian Conditions

Shoreline vegetation provides habitat structure and function for salmon and salmon prey. Research has shown that surf smelt egg survival is reduced up to 50% along armored shorelines (Rice 2006). The removal of shoreline, or riparian vegetation, is often associated with shoreline armoring. Existing data sets on marine riparian vegetation in San Juan County provide information on the presence of overhanging vegetation at the shoreform, not parcel, scale. For this analysis, overhanging marine vegetation conditions was analyzed for just those geomorphic shoreforms with documented forage fish spawn habitat. Results are presented below in Tables 10 and 11 at the county, and shoreform scale, respectively.

Table 10. County-wide Shoreforms with Spawn and Overhanging Marine Riparian Vegetation

Shoreforms w/documented forage fish spawn	Shoreform Count	Shoreform Percent*
> 75% OHV	90	59%
51-75% OHV	16	10%
26-50% OHV	12	8%
.1-25% OHV	27	18%
No OHV	8	5%
total	153	100%

Nearly 60% of shoreforms with documented spawn have overhanging marine vegetation classified as greater than 75%. However, nearly 25% of shoreforms with documented spawn have overhanging vegetation conditions classified as none or less than 25%. Feeder bluffs and transport zones were the shoreform type with highest overhanging vegetation on shoreforms with spawn (71 and 70% respectively), while 60 % of pocket beaches and just 16% of barrier beaches with spawn had the highest classification of overhanging marine riparian vegetation (75-100%). Please note that some shoreforms such as barrier beaches (e.g. spits) have naturally low overhanging vegetation conditions.

Figure 18. Shoreforms with Spawn and Overhanging Marine Riparian Vegetation Condition

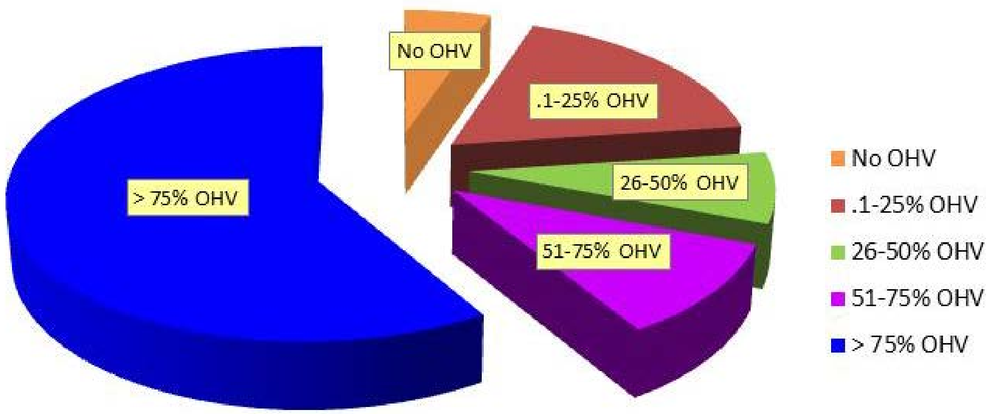


Table 11. Overhanging Marine Riparian Vegetation in Shoreforms with Documented Spawn

Shoreforms w/documented forage fish spawn	> 75 OHV	51-75% OHV	26-50% OHV	.1-25% OHV	No OHV	Total shoreform with spawn
Artificial	0	0	0	1	0	1
Barrier beach	4	2	1	12	6	25
Transport zone	24	4	4	1	1	34
Feeder bluff	32	5	1	7	0	45
Embayment	0	0	0	0	1	1
Pocket beach	26	5	6	6	0	43
Rocky shores	4	0	0	0	0	4
Total	90	16	12	27	8	153

Armor and Overhanging Marine Riparian Vegetation

To help evaluate potential impacts to forage fish spawning success, and improve understanding of the relationship between armoring and shoreline vegetation, a visual assessment of overhanging vegetation at armored and unarmored documented forage fish spawning sites was completed. Visual assessment was conducted using oblique and vertical aerial photographs from the Washington Department of Ecology as well as infrared vertical aerials (Friends of the San Juans and the WA Department of Natural Resources). Overhanging vegetation presence was classified into five categories (none, .1 to 25%, 26-50%, 51-75% and 75-100%).

Changes to overhanging vegetation at armored documented spawn sites was most pronounced for feeder bluff, pocket beach and rocky shoreforms. See Table 12 Overhanging Marine Riparian Vegetation; note results shown as for the dominant coverage classes only.

Table 12. Overhanging Marine Riparian Vegetation: Dominant Coverage, Armor and Spawn (coverage classes: none; .1-25%; 26-50%; 51-75%; 76-100%)

Shoreform	Overhanging Vegetation Shoreform with Spawn*	Overhanging Vegetation Unarmored Spawning Beaches*	Overhanging Vegetation Armored Spawning Beaches*
Artificial	none	none	n/a
Embayment	n/a	n/a	n/a
Feeder Bluff	76-100%	76-100%	.1-25%
Transport Zone	76-100%	76-100%	76-100%
Barrier Beach	none	none	none
Pocket Beach	76-100%	76-100%	None
Rocky Shore	76-100%	76-100%	none

Note: table simplified to show dominant coverage class results only. No known spawn in embayments.

Conclusions and Management Implications

With over 700 armored beaches (23 miles) and a limited number of documented forage fish spawning beaches (10 miles), improved efforts to understand and manage the cumulative effects of shoreline armoring to these critical spawning habitats and habitat forming processes are needed. Forage fish play a critical role in marine foods, with a small number of forage fish species providing the critical link between zooplankton and the predators, including seabirds, marine mammals and a multitude of fish species including Chinook salmon. Improved management, including both restoration and protection strategies, regulatory and voluntary, are needed to reduce the impacts of bulkheads and shoreline infrastructure on beach spawning habitat and the coastal processes that form and maintain suitable spawning substrate over time. Key findings of this cumulative impact assessment and associated management implications are discussed below.

Shoreline Development Patterns

As the majority of shoreline tax parcels in San Juan Count are in private, primarily residential ownership, the role of individual landowners (and the regulatory and voluntary policies and programs that influence their land management behaviors) cannot be overstated. The fact that one third of developable, private, shoreline parcels have not yet had a primary structure developed on the site provides a major opportunity to influence future demand for shoreline armoring; the strong relationship between existing development setback and shoreline armoring indicates that an effective tool to achieve this demand reduction is through expanded building setbacks. A combination of restoration, enhancement and improved protection actions could likely be applied to conservation, education and public shoreline ownerships, as well as much private ownership. Relocation and redesign of public shoreline road infrastructure provides a significant habitat restoration and enhancement opportunity, as well as demonstration and research value and a prudent application of resources in the face of sea level rise and associated climate change impacts to erosion and flood hazard areas in the county.

Armor Permit Trends

Analysis of the San Juan County permit trends for shoreline armoring demonstrate that updated Shoreline Master Program and Critical Areas Ordinances (with forage fish specific language) did not result in a reduction in the rate or number of shoreline armoring occurrences in the county. As shoreline development continues, and demand for armor continues to increase, additional tools (regulatory and voluntary) will be needed to ensure protection of forage fish spawning habitat and the processes that form and maintain spawning beaches. The high volume of exemptions highlights two primary management implications, first, the need to ensure that exemptions adhere to the protection requirements of the Shoreline Management Act, if not the permit fee and process, and second, that repair and replacement of private bulkheads provides a significant threat to habitat (as impacts are typically increased as logs are replaced with large rip rap), as well as a significant enhancement or possible even restoration opportunity (through regulatory or voluntary programs that ensure new structures are necessary and if so, designed in as landward and habitat-friendly configuration as possible). The large number of code violations associated with shoreline armoring points to a need for dramatically improved enforcement, as well as expanded education and awareness. Inconsistencies in the information entered into the permit record restricts the type and quality of analysis even possible; improvements and standardization of data records, to include precise locational information, structure length, and tidal elevation of the toe of armor, would greatly improve the county's capacity to track cumulative effects and changes over time along local shorelines.

Armor Impacts to Forage Fish Spawning Habitat

With just 10 miles of documented forage fish spawning habitat, 15% which are already impacted by shoreline armoring, increased efforts to protect the incubating eggs of this critical component of marine food webs in San Juan County are needed. Impacts of shoreline armoring (through residential bulkheads and roads) on forage fish spawning habitat include the direct burial of eleven acres of spawning grounds, as well as numerous disruptions to the coastal sediment supply and transport processes that form and maintain suitable spawning substrate over time. Longer term risks exist at armored sites from rising sea levels. Significant protection opportunities exist, through increased building setbacks on undeveloped, residential properties to reduce demand for future armoring as well as improved implementation and/or strengthening of protection policies and regulations and enforcement designed to reduce demand for armoring and retain shoreline vegetation. Significant restoration and enhancement opportunities also exist, primarily through relocation of public coastal roads and the landward relocation/redesign of residential bulkheads in need of repair or replacement. Example project actions to address the impacts of armor on forage fish spawning habitat in San Juan County are provided below, organized by project type.

Protection

Protection of beach habitats into the future, for fish, wildlife and people will not be possible through restoration actions alone; the Puget Sound Partnership estimates that despite extensive habitat restoration efforts new armoring still outpaces armor removal at a ten to one ratio. Demand for armoring is expected to increase as a result of increased shoreline development and sea level rise impacts. As restoration success is limited by both physical and ecological feasibility and high cost, improved protection actions will play an essential role in ensuring that forage fish spawning habitat and habitat forming processes are maintained into the future. Recommendations for protection supported by this analysis include:

- Regulatory protections that clearly prohibit the construction of new bulkheads at documented forage fish spawning sites or at feeder bluffs in drift cells with document spawning sites.
- Design policies with a focus on minimizing the need for future armoring at all shoreforms and drift cells such as expanded building setbacks and enhanced protection of vegetative buffers between structures and the shoreline.

- Many conservation properties (easement and ownership) were established before forage fish spawning habitat was documented; review and updating of management plans to ensure consistency with habitat protection are needed.
- Improve and greatly expand regulatory protection policies and voluntary incentives, as well as voluntary stewardship and conservation programs will be required to address both existing impacts as well as expanded future demand for armoring. Existing tools include using the Open Open Space public benefit rating system to promote shoreline protections, updating the Shoreline Master Program and Critical Areas rules to better protect forage fish habitat and expanding public support of permanent protection of spawning grounds through acquisition or easement.

<u>Restoration</u>

Recommended restoration actions include a combination of private bulkheads and public road project types. Top restoration priorities include:

- Remove armoring from documented forage fish spawning beaches to uncover and restore buried spawning substrate.
- Remove shoreline armoring from feeder bluffs in drift cells with documented forage fish spawning habitat to restore sediment supply.
- Remove shoreline armoring located below mean sea level updrift of documented spawning sites to restore sediment transport.
- Remove armoring from feeder bluffs and removal of all armoring with a toe elevation less than mean sea level in drift cells with potential forage fish spawning habitat, to ensure coastal processes are intact throughout the system as additional spawn sites are likely.

<u>Enhancement</u>

Potential enhancement actions include:

- Improve overhanging vegetation along armored sites with documented spawn habitat where armor removal is not feasible. This is especially important for feeder bluffs, pocket beaches and rocky shoreforms with spawn; where significant reductions in overhanging vegetation at armored known spawning sites was documented.
- Relocate or redesign shore protection landward or using soft-shore protection techniques; significant opportunity provided by regulatory updates to repair/replace procedures.
- Consider beach nourishment in drift cells with armored feeder bluffs that cannot be restored or those cells with armor or groins limiting the long shore movement of sediment. Note- suitable nourishment sites were not assessed as part of this project.

Application of Results

This spatially explicit analysis of the impacts of armor on forage fish spawning habitat begins to articulate relationships between key variables including forage fish spawning habitat, shoreline armoring and development patterns support the development and implementation of a more strategic approach to long term protection of habitat and habitat forming processes essential for beach spawning forage fish. Results have clear policy implications, as well as guidance for project-level prioritization of effort, such as salmon recovery. Project results will be used by the project partners and team, in combination with results of other research elements (sea level rise vulnerability assessment, regulatory review, and tidal elevation of surf smelt spawn study) to inform the development of specific management recommendations to improve effectiveness of existing regulations. Results also have direct application to the current Shoreline Master Program update underway in San Juan County.

References

Bargmann, G. 1998. Forage Fish Management Plan. A plan for managing the forage fish resources of Washington. Washington Department of Fish and Wildlife. Olympia, WA. 66 p.

Bruun, P., 1962. Sea-level rise as a cause of shore erosion. Journal Waterways and Harbors Division, 88**,** (1-3)**,** 117.

Bulleri, F. and M.G. Chapman. 2010. The introduction of coastal infrastructure as a driver of change in marine environments. Journal of Applied Ecology 2010, 47, 26-35.

Cooper, N.J. 2003. The use of 'managed retreat' in coastal engineering. Proceedings of the Institution of Civil Engineers Engineering Sustainability 156 Issue ES2 p. 101-110

Cox J., and M Baker Jr, 1996. Shoreline Armoring Effect and Engineering Techniques for Shoreline Erosion Management In Project Puget Sound, Seeking Balance: Conflict, Resolution & Partnership conference proceedings, p. 60-70.

Downing, J., 1983. The Coast of Puget Sound, Its Processes and Development. Washington Sea Grant Publication, University of Washington Press, Seattle, 126 pp.

Fletcher, C.H., R.A. Mullane, B.M. Richmond, 1997. Beach loss along armored shoreline on Oahu, Hawaiian Islands, Journal of Coastal Research, vol. 13, no. 1, p. 209-215.

Fresh, K.L. 2006. Juvenile Pacific Salmon in Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-06. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Friends of the San Juans. 2004. Forage Fish Spawning Habitat Assessment and a Summary of Protection and Restoration Priorities for San Juan County Washington. Final Project Report. Friday Harbor, WA.

Griggs, G.B., 2005. The impacts of coastal armoring. *Shore and Beach*, vol. 73, no. 1, Winter, p. 13-22.

Glick, P., J. Clough and B. Nunley. 2007. Sea-level Rise and Coastal Habitats in the Pacific Northwest: An Analysis for Puget Sound, Southwestern Washington, and Northwestern Oregon. National Wildlife Federation.

Hampton, Monty, Griggs, Gary, Edil, Tuncer, Guy, Donald, Kelly, Joseph, Komar, Paul, Mickleson, David, and Shipman, Hugh, 2004. Processes that Govern the Formation and Evolution of Coastal Cliffs: Formation, Evolution, and Stability of Coastal Cliffs—Status and Trends, Hampton, Monty A. and Griggs, Gary B. (editors), USGS Professional Paper 1693, p. 7-38.

Hosking, A. & R. McInnes, 2002. Preparing for the Impacts of climate change on the Central Southeast of England: A framework for future risk management. *Journal of Coastal Research,* Special issue 36, 381-389.

IPCC (Intergovernmental Panel on Climate Change), 2001. Climate change 2001: The scientific basis. Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Houghton, J. T., Y. Ding, D. J. Griggs, M. Noguer, P. J. can der Linden, X. Dai, K. Maskell, and C. A. Johnson (eds). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 881 p.

Johannessen, J.W. and A.J. MacLennan, 2006. Soft Shore Protection/Structure Removal Blueprint for San Juan County Forage Fish Beaches. Prepared for Friends of the San Juans, 40 p.

Johannessen, J. and A. MacLennan. 2007. Beaches and Bluffs of Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-04. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Krueger, K., K. Pierce, T. Quinn and D. Penttila. 2009. Anticipated effects of sea level rise in Puget Sound on two beach-spawning fishes. IN: Puget sound shorelines and the impacts of armoring- proceedings of a state of the science workshop, May 2009. Science investigations report 2010-5254. U.S. Department of the Interior. U.S. Geological Survey.

Legget, D.J., N. Cooper and R. Harvey. 2004.Coastal and estuarine managed realignment- design issues. CIRIA. London

Leschine, T.M. and A.W. Petersen. 2007. Valuing Puget Sound's Valued Ecosystem Components. Puget Sound Nearshore Partnership Report No. 2007-07. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

MacDonald, K. D. Simpson, B. Paulsen, J. Cox, and J. Gendron, 1994. Shoreline Armoring Effects on Physical Coastal Processes in Puget Sound, Washington. Coastal Erosion Management Studies Volume 5. Shorelands and Water Resources Program, Washington Department of Ecology, Olympia. Report # 94-78.

MacLennan, A.J., J. W. Johannessen, 2008. San Juan Initiative Protection Assessment Nearshore Case Study Area Characterization, Final Report Prepared for The San Juan Initiative; The Puget Sound Partnership through The Surfrider Foundation, 54 p. plus appendices.

MacLennan, A and J. Waggoner. 2013. Sea Level Rise Vulnerability Assessment for San Juan County Washington. Prepared by Coastal Geologic Services for Friends of the San Juan's EPA and WDFW Project #12-1102.

Moulton, L. L. and D. E. Penttila, 2001. Field manual for sampling forage fish spawn in intertidal shore regions and the Distribution of potential surf smelt and Pacific sand lance spawning habitat in San Juan County. MJM Research and Washington Department of Fish and Wildlife for the San Juan County Forage Fish Project.

Penttila, D.E. 1999. Documented spawning areas of the Pacific herring (Clupea), surf smelt (Hypomesus), and Pacific sand lance (Ammodytes) in San Juan County, Washington. Washington Dept. of Fish and Wildlife, Marine Resources Division. Manuscript Report. LaConner, WA. 27p.

Penttila, D. 2007. Marine Forage Fishes in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-03. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Pethick, J., 2001. Coastal management and sea-level rise. *Catena,* 42, 307-322

Plant, N.G. and Griggs, G. B. 1992. Interactions between nearshore processes and beach morphology near a seawall. *Journal of Coastal Research*, No. 8: 183-200.

Puget Sound Partnership. 2009. Action Agenda for Puget Sound.

Redman, Scott, and Fresh, Kurt, 2005. Regional Nearshore and Marine Aspects of Salmon Recovery, Puget Sound Action Team and NOAA Fisheries Olympia/Seattle.

Rice, C. 2006. Effects of Shoreline Modification on a Northern Puget Sound Beach: Microclimate and Embryo Mortality in Surf Smelt (Hypomesus pretiosus). Estuaries and Coasts. Vol 29, No. 1. p. 63-71.

San Juan County Community Development and Planning. 2010. Permit Center Databases.Friday Harbor, Washington.

San Juan County Marine Resources Committee. 2007. Marine Stewardship Area Conservation Action Plan. San Juan County and The Nature Conservancy, Friday Harbor, Washington.

San Juan Initiative. 2008. San Juan Initiative Protection Assessment Nearshore Case Study Area Characterization. San Juan County and the Puget Sound Partnership.

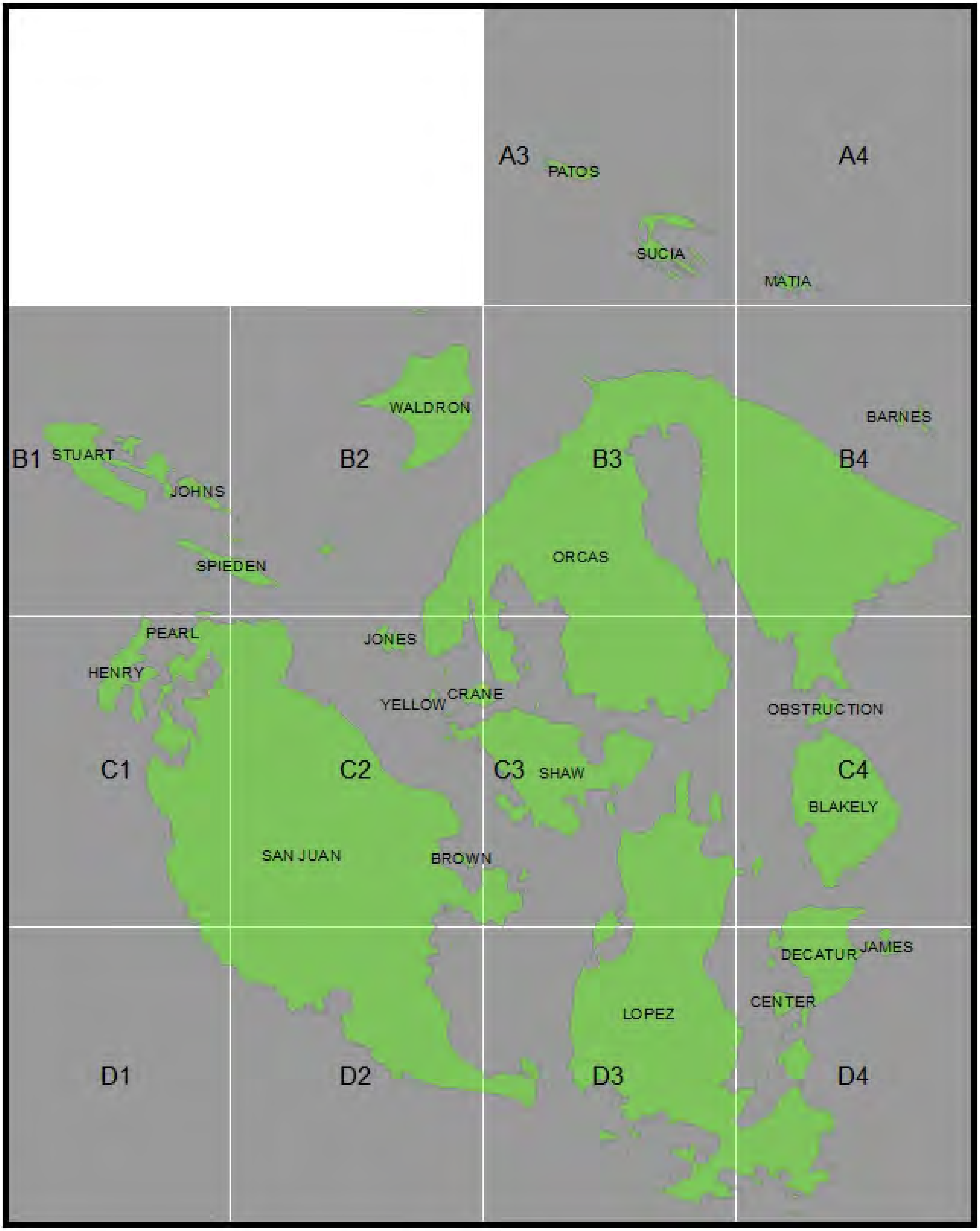
Shared Strategy. 2005. Puget Sound Chinook salmon recovery plan. Seattle, Washington.

Stone, G. W., J. P. Morgan, A. Sheremet & X. Zhang, 2003. Coastal land loss and wave-surge predictions during hurricanes in Coastal Louisiana: implications for the oil and gas industry. Baton Rouge: Coastal Studies Institute, Louisiana State University. 67pp

Thom, R., Shreffler, D., and Macdonald, Keith, 1994. Shoreline armoring effects on coastal ecology and biological resources in Puget Sound, Washington: Coastal Erosion Management Studies.

Whitman, T. 2007. Analysis of Shoreline Permit Activity in San Juan County, Washington (1972-2005). Friends of the San Juans. Friday Harbor, WA.

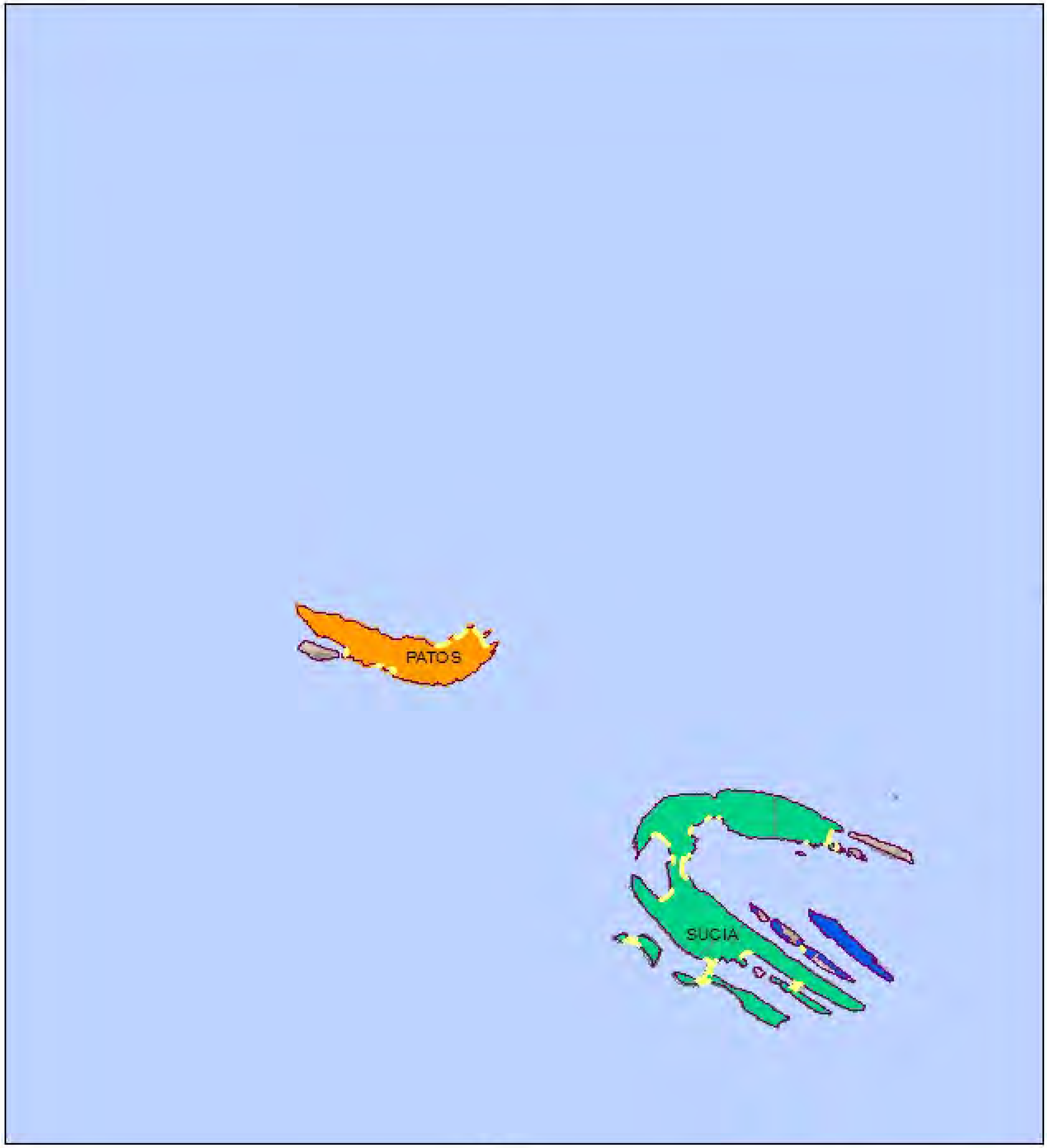
Whitman, T, MacLennan, A. Schlenger, P., Small, J. Hawkins, S. and J. Slocomb. Strategic salmon recovery planning project for San Juan County Washington: the Pulling It All Together (PIAT) project. Friends of the San Juans, Coastal Geologic Services, Confluence Environmental and Anchor QEA. Prepared for the SJC Lead Entity for Salmon Recovery and the Washington State Salmon Recovery Funding Board RCO-10-1789.



San Juan County Shoreline Development Status

MAP BOOK

Shoreline Development Status



A4

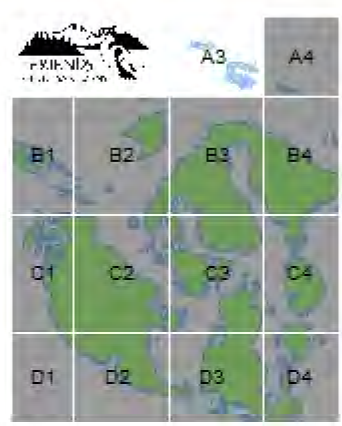
B2 B3 B4

1 0.5 0 1 Miles

N

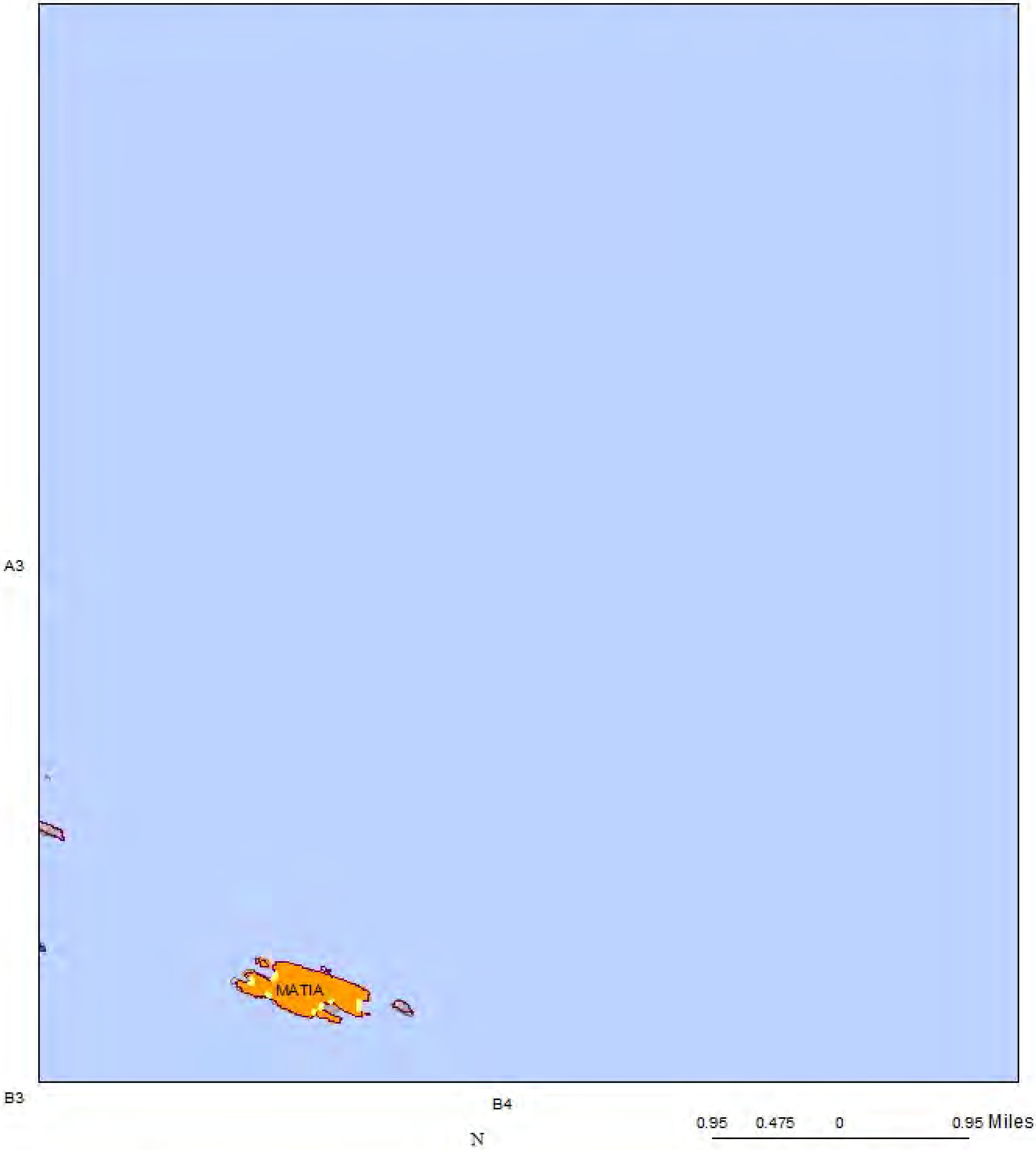
Legend

- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- Privately Owned Lands - Developed
- Privately Owned Lands - Undeveloped
- Public or Conservation Ownership
- Artificial Shoreline
- Rocky Shoreline



A3

Shoreline Parcel Development Status



Legend

Documented Forage Fish Habitat

Potential Forage Fish Habitat

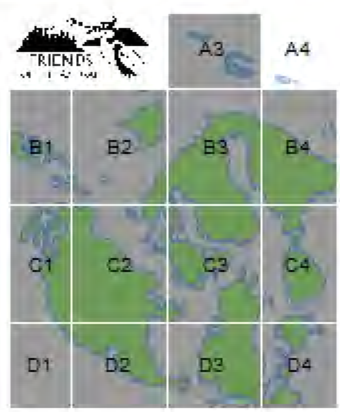
Privately Owned Lands - Developed

Privately Owned Lands - Undeveloped

Public or Conservation Ownership

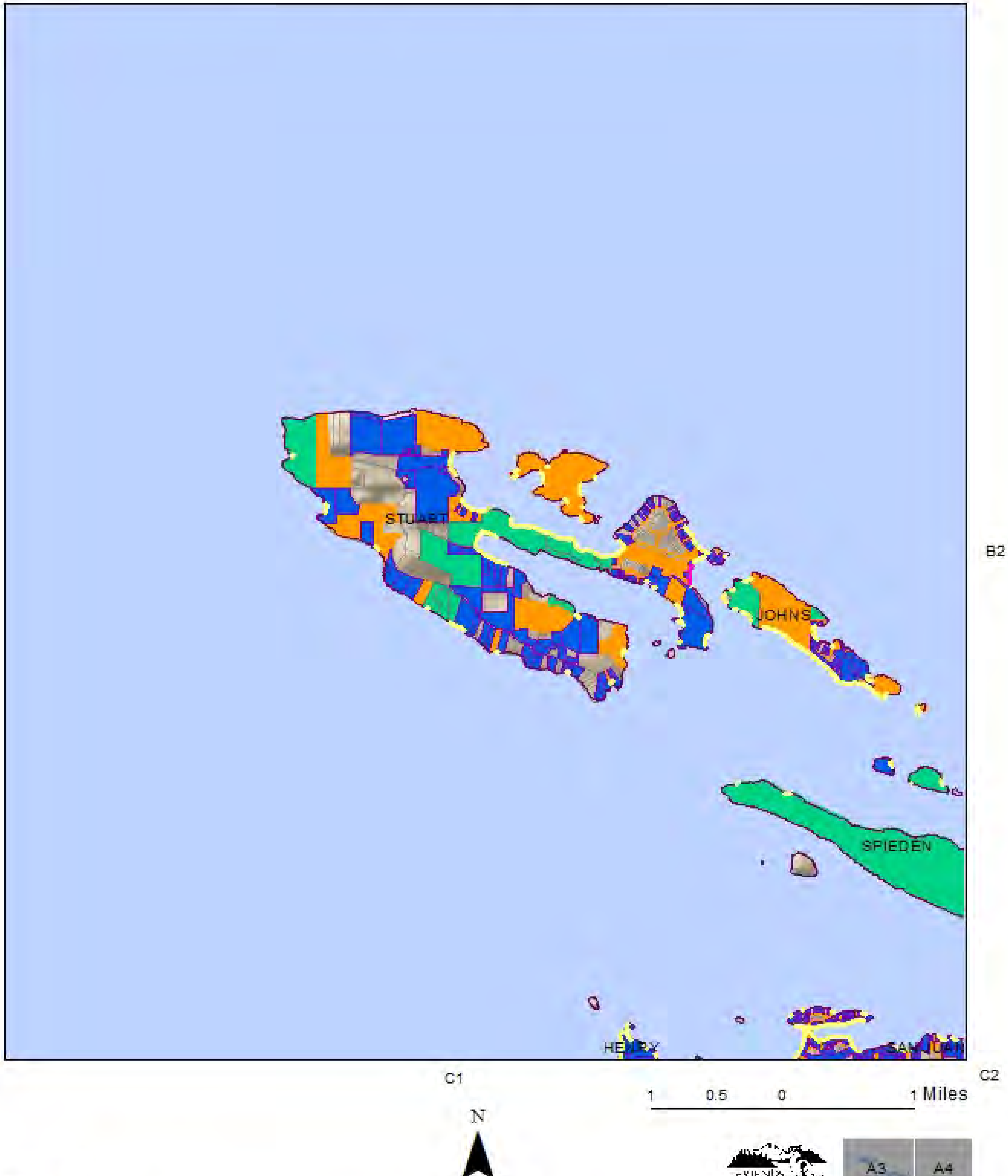
Artificial Shoreline

Rocky Shoreline



A4

Shoreline Development Status

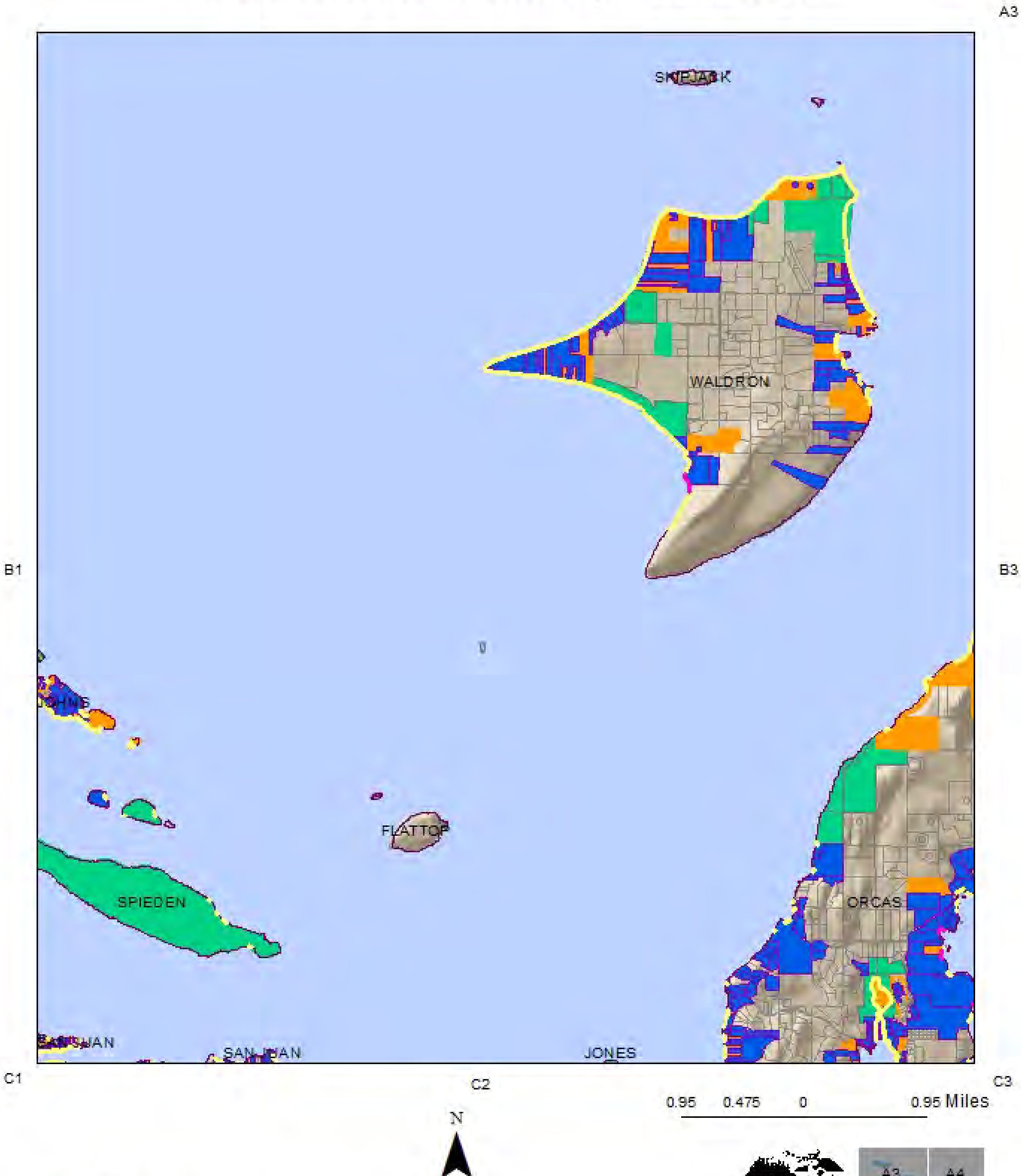


Legend

- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- Privately Owned Lands - Developed
- Privately Owned Lands - Undeveloped
- Public or Conservation Ownership
- Artificial Shoreline
- Rocky Shoreline

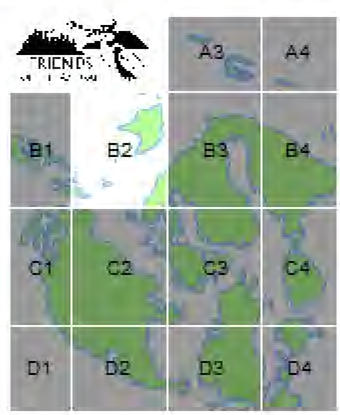
B1

Shoreline Parcel Development Status



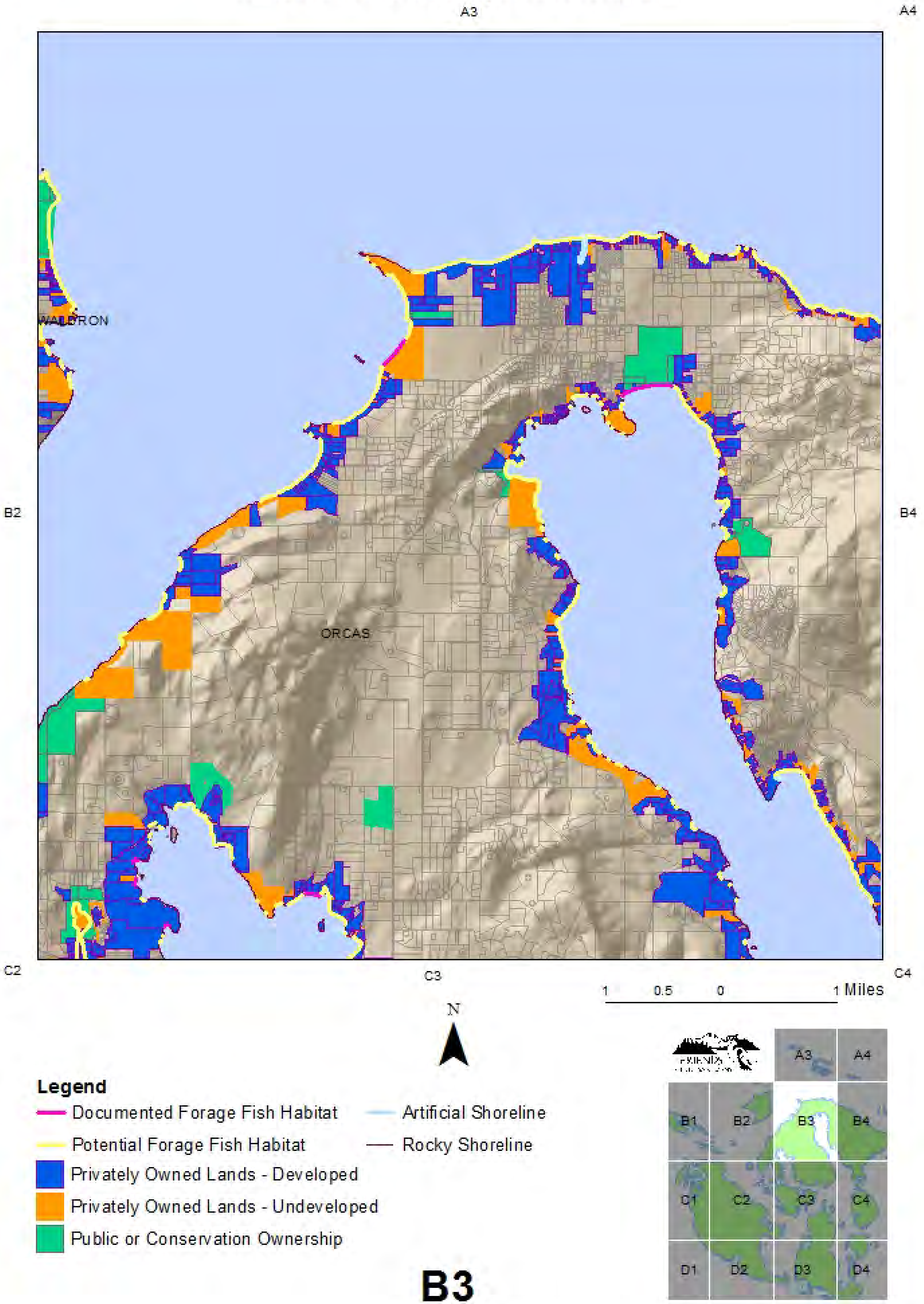
Legend

- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- Artificial Shoreline
- Rocky Shoreline
- Privately Owned Lands - Developed
- Privately Owned Lands - Undeveloped
- Public or Conservation Ownership



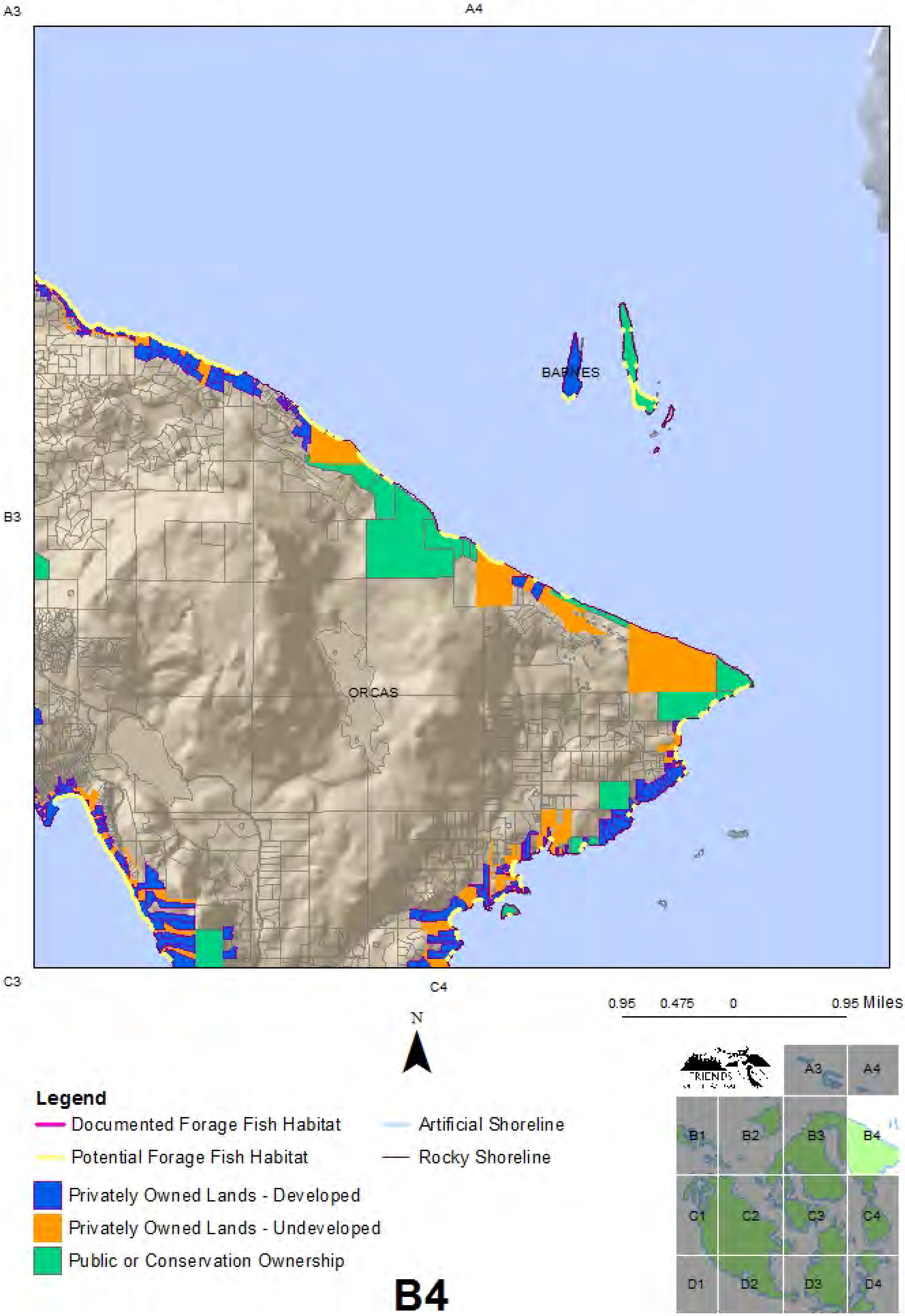
B2

Shoreline Development Status

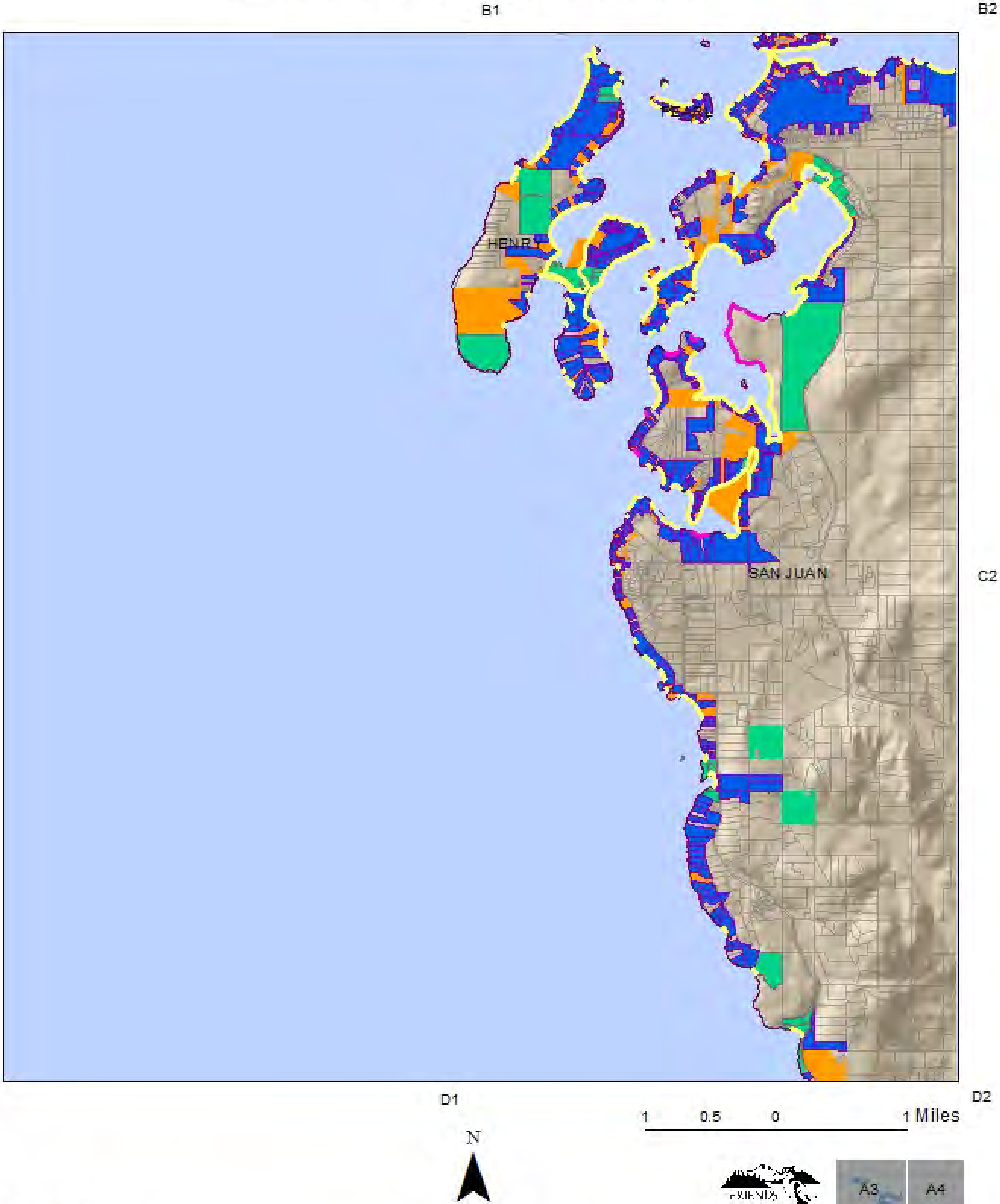


B3

Shoreline Parcel Development Status

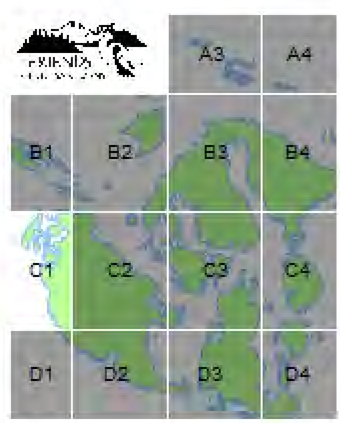


Shoreline Development Status



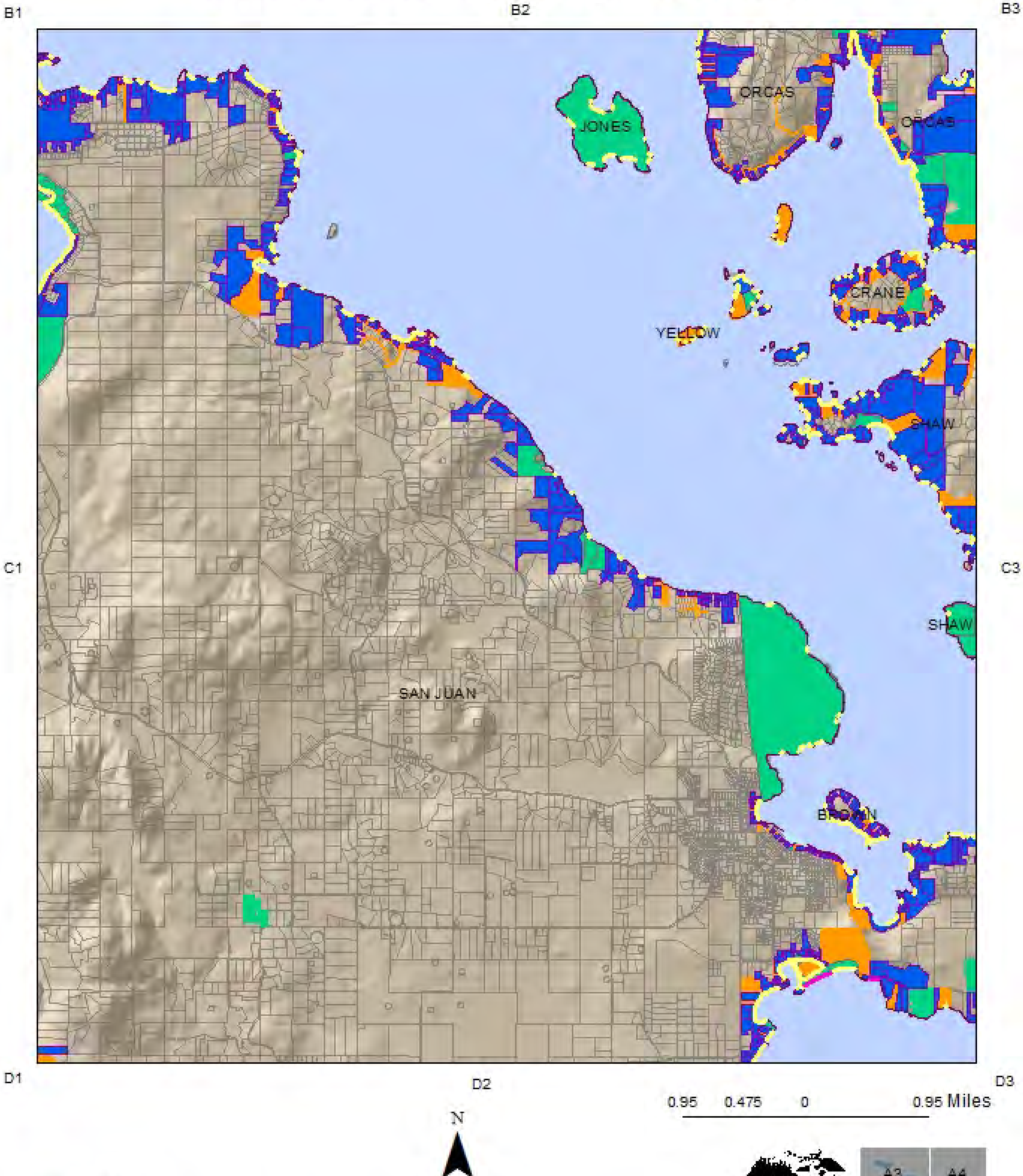
Legend

- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- Privately Owned Lands - Developed
- Privately Owned Lands - Undeveloped
- Public or Conservation Ownership
- Artificial Shoreline
- Rocky Shoreline



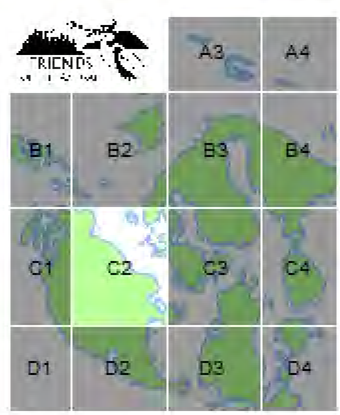
C1

Shoreline Parcel Development Status



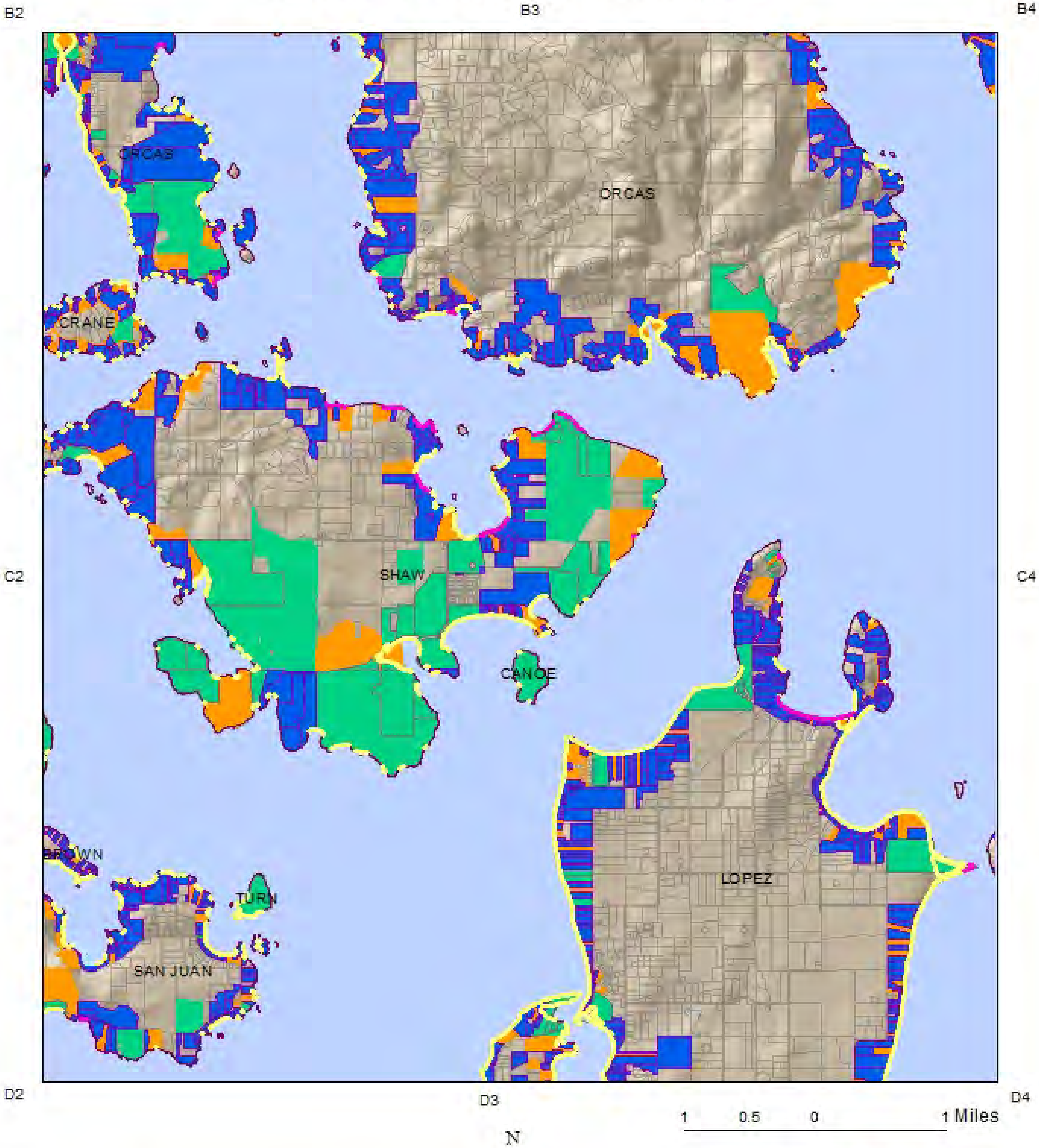
Legend

- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- Privately Owned Lands - Developed
- Privately Owned Lands - Undeveloped
- Public or Conservation Ownership
- Artificial Shoreline
- Rocky Shoreline



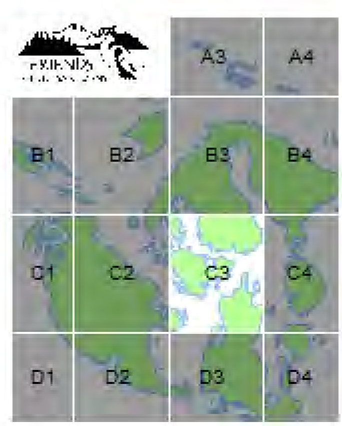
C2

Shoreline Development Status



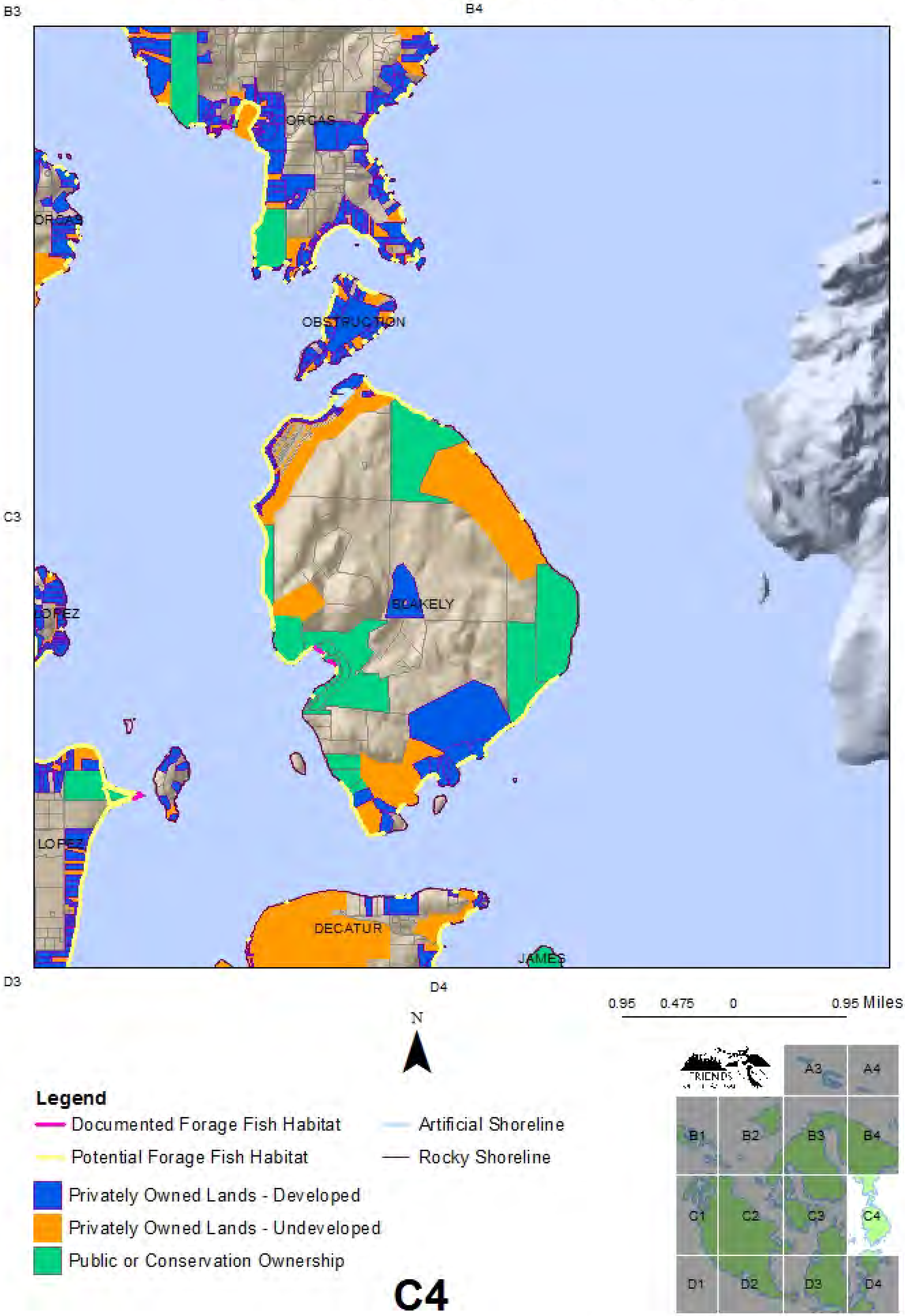
Legend

- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- Privately Owned Lands - Developed
- Privately Owned Lands - Undeveloped
- Public or Conservation Ownership
- Artificial Shoreline
- Rocky Shoreline



C3

Shoreline Parcel Development Status

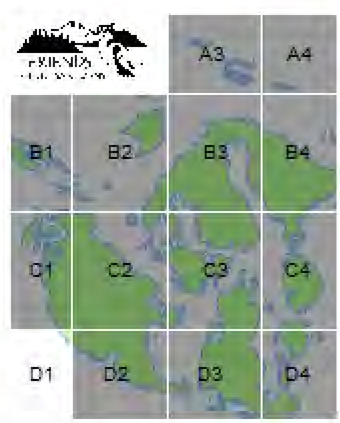


C4

Shoreline Development Status

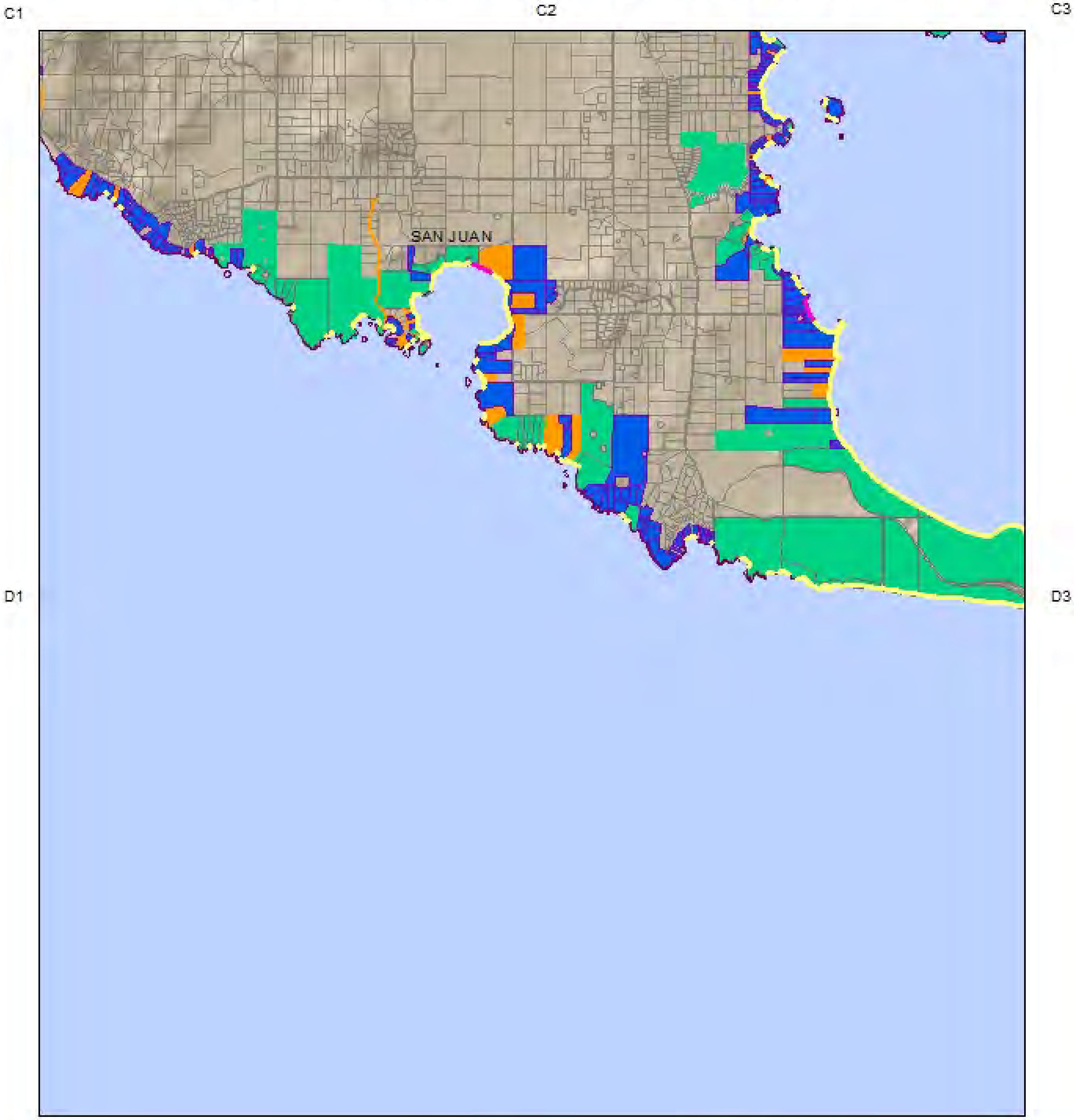
Legend

- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- Privately Owned Lands - Developed
- Privately Owned Lands - Undeveloped
- Public or Conservation Ownership
- Artificial Shoreline
- Rocky Shoreline



D1

Shoreline Parcel Development Status

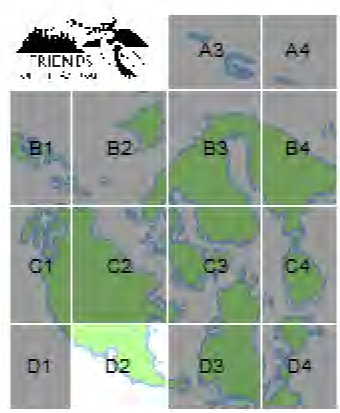


0.95 0.475 0 0.95 Miles

N

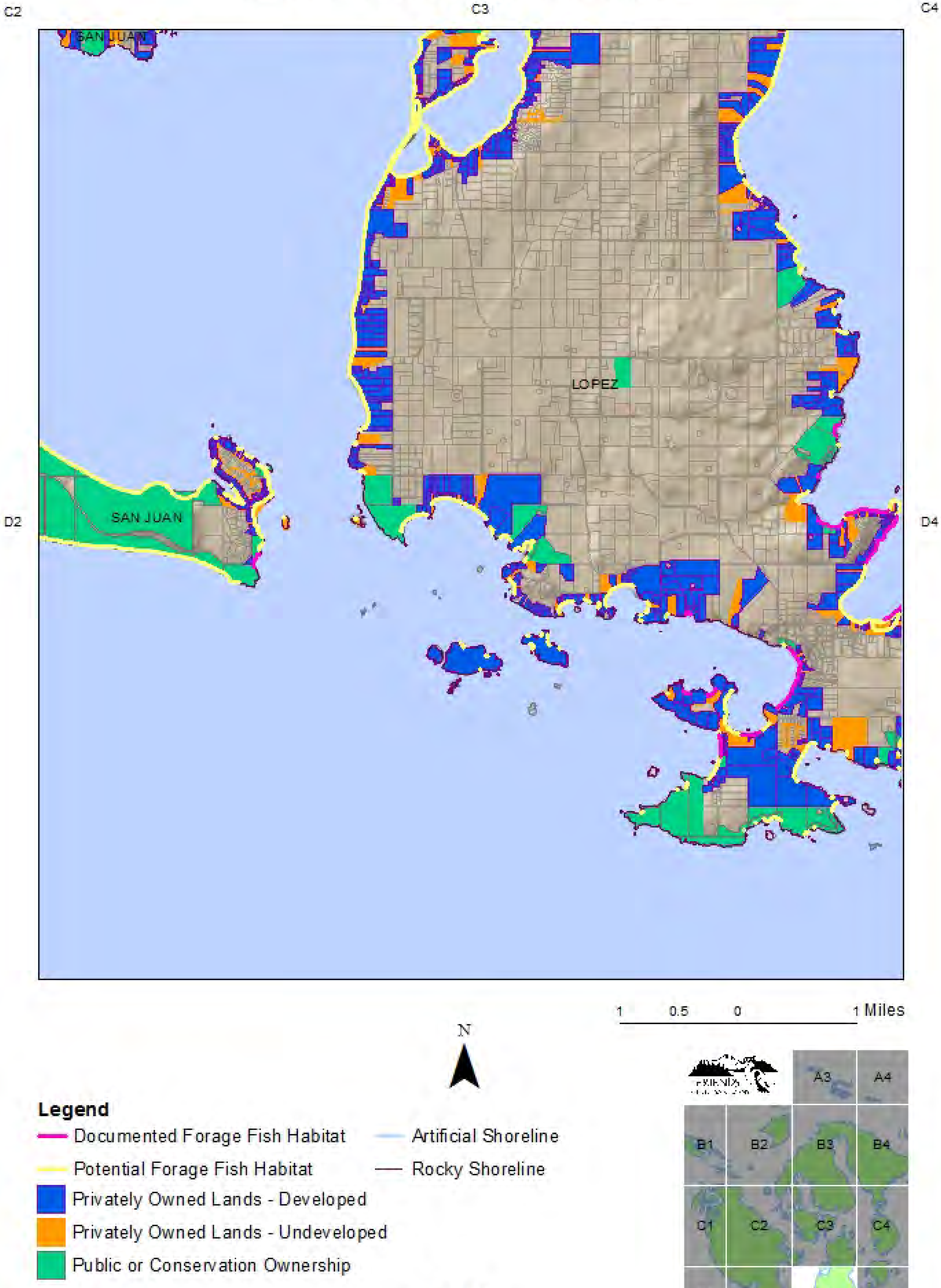
Legend

- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- Artificial Shoreline
- Rocky Shoreline
- Privately Owned Lands - Developed
- Privately Owned Lands - Undeveloped
- Public or Conservation Ownership



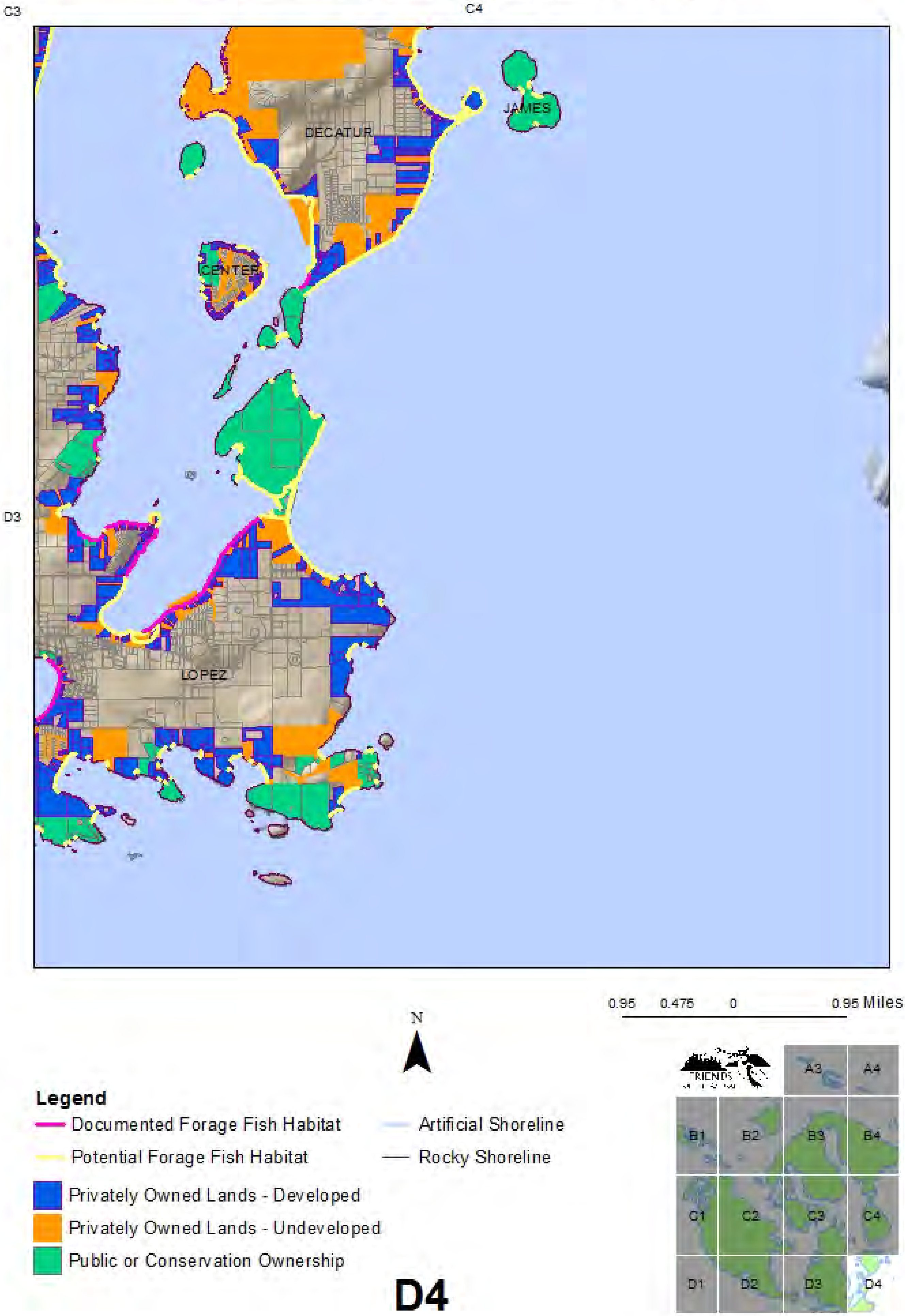
D2

Shoreline Development Status



D3

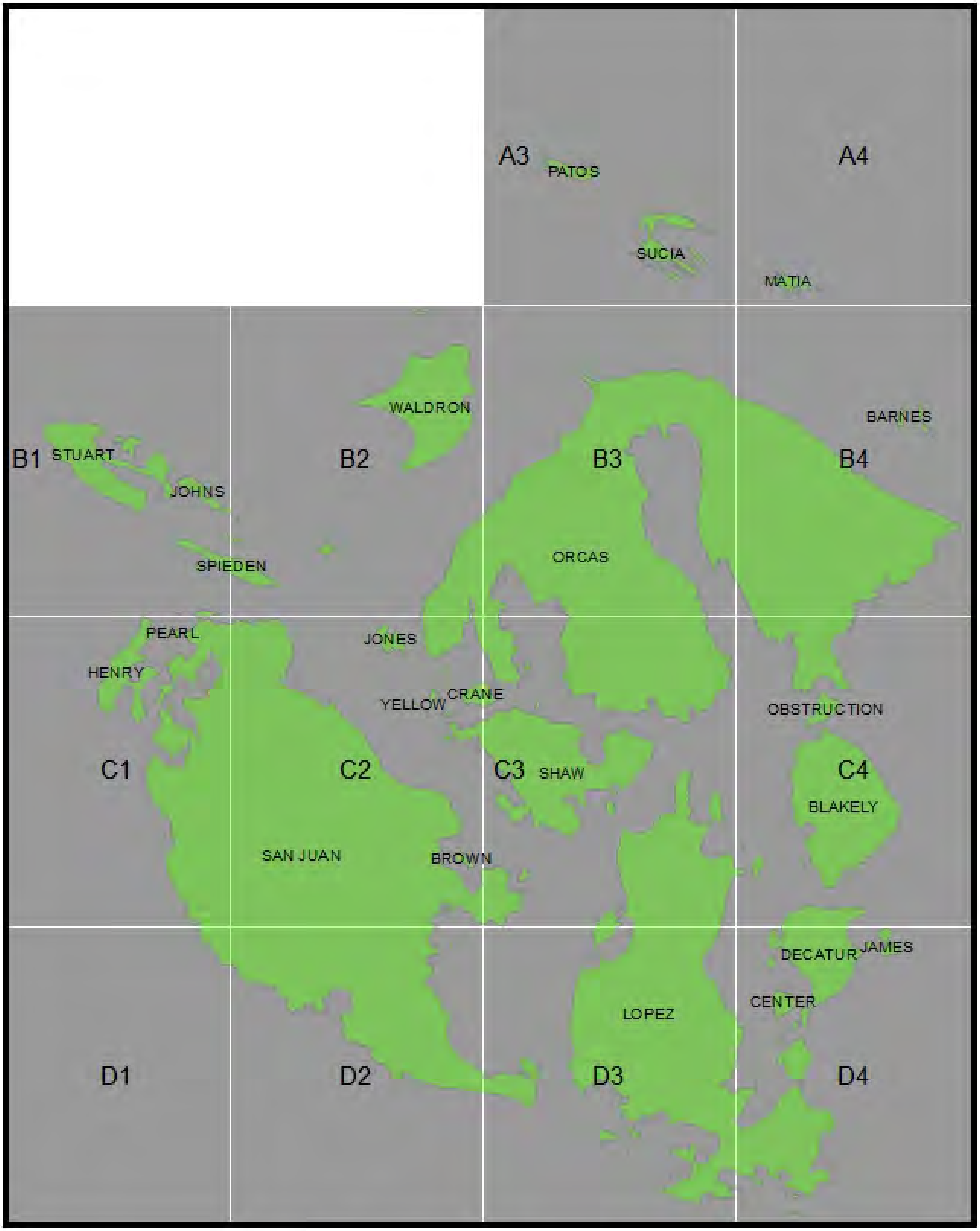
Shoreline Parcel Development Status



Legend

- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- Artificial Shoreline
- Rocky Shoreline
- Privately Owned Lands - Developed
- Privately Owned Lands - Undeveloped
- Public or Conservation Ownership

D4



San Juan County
Parcels With Armor And Building Setback
(data shown for parcels with armor and structure only)
MAP BOOK

Parcels With Armor And Building Setback

Legend (data shown for parcels with armor and structure only)

ARMOR

Documented Forage Fish Habitat

Potential Forage Fish Habitat

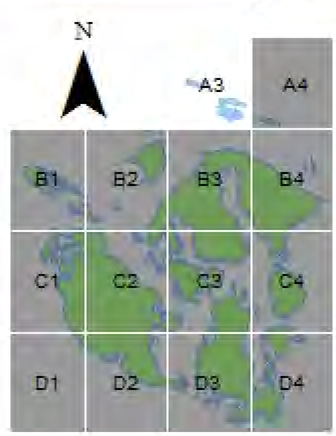
BUILDING DISTANCE FROM SHORELINE

Parcel With Bldg. Within 50 ft.

Parcel With Bldg. 50 ft. to100 ft.

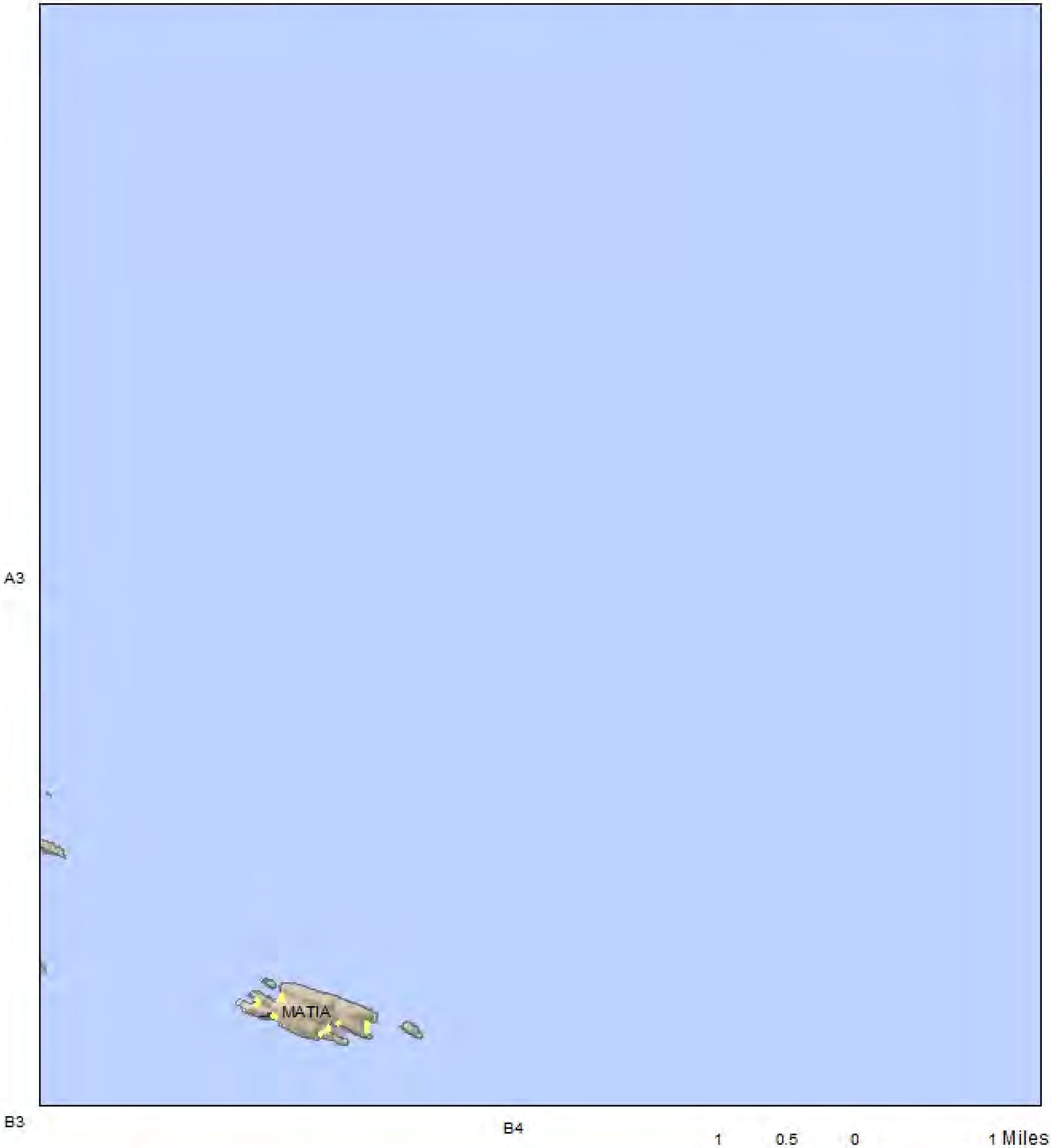
Parcel With Bldg. 100 ft. to 200 ft.

Parcel With Bldg. 200 ft. to 500 ft.



A3

Parcels With Armor And Building Setback

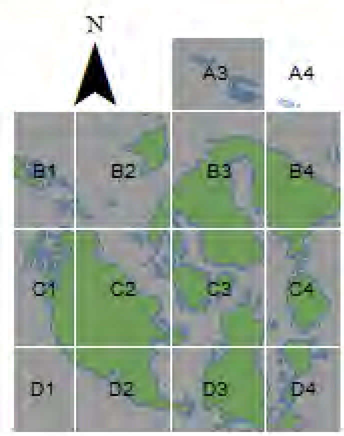


Legend (data shown for parcels with armor and structure only)

- ARMOR
- Documented Forage Fish Habitat
- Potential Forage Fish Habitat

BUILDING DISTANCE FROM SHORELINE

- Parcel With Armor and Bldg. Within 50 ft.
- Parcel With Armor and Bldg. 50 ft. to100 ft.
- Parcel With Armor and Bldg. 100 ft. to 200 ft.
- Parcel With Armor and Bldg. 200 ft. to 500 ft.



A4

Parcels With Armor And Building Setback

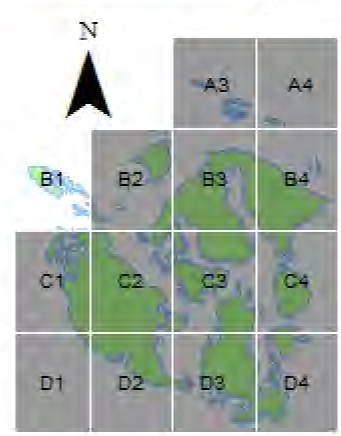
Legend (data shown for parcels with armor and structure only)

ARMOR

Documented Forage Fish Habitat
Potential Forage Fish Habitat

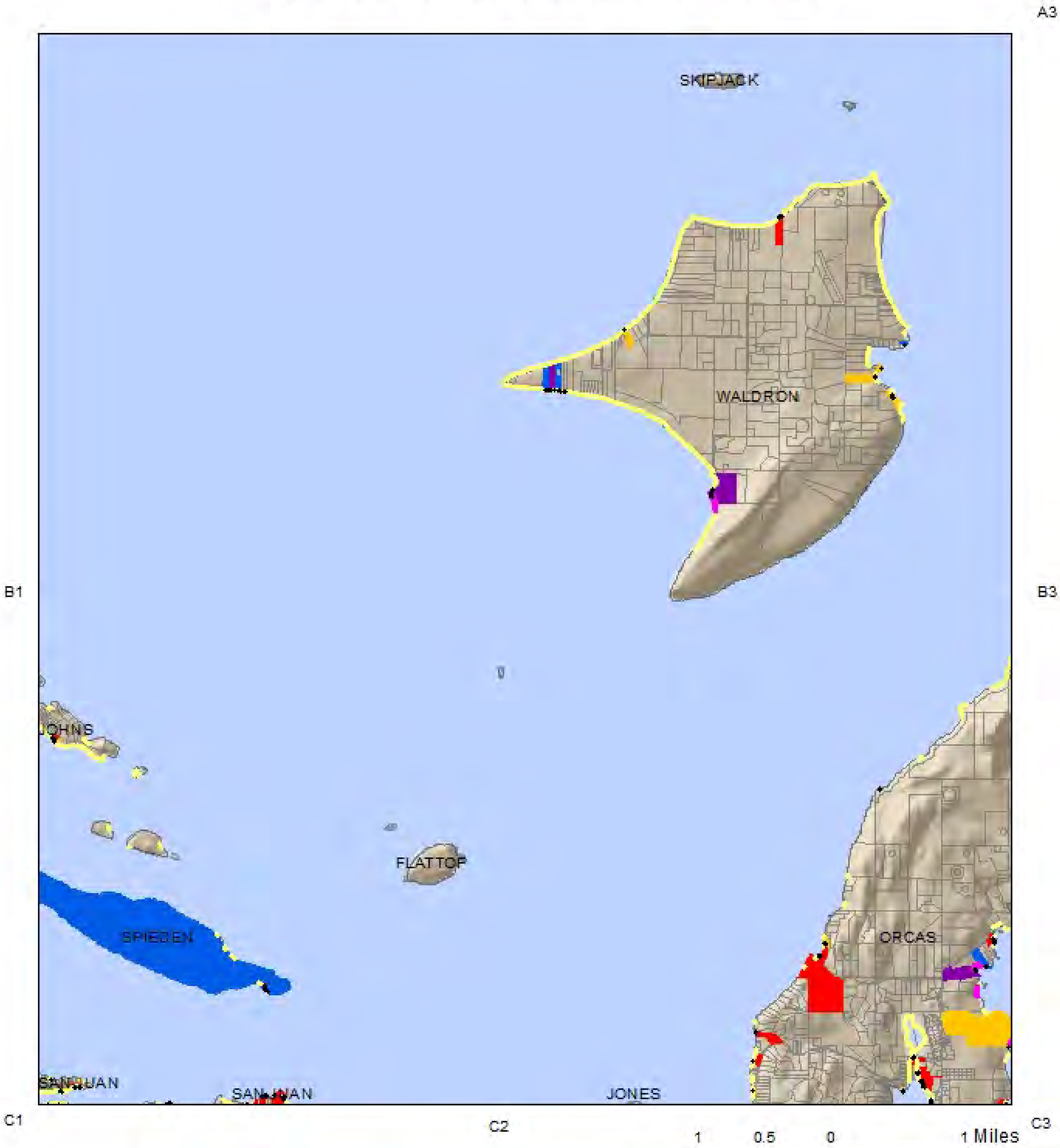
BUILDING DISTANCE FROM SHORELINE

Parcel With Bldg. Within 50 ft.
Parcel With Bldg. 50 ft. to100 ft.
Parcel With Bldg. 100 ft. to 200 ft.
Parcel With Bldg. 200 ft. to 500 ft.



B1

Parcels With Armor And Building Setback



Legend (data shown for parcels with armor and structure only)

ARMOR

Documented Forage Fish Habitat Potential Forage Fish Habitat

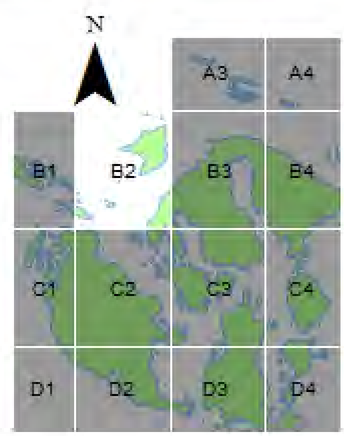
BUILDING DISTANCE FROM SHORELINE

Parcel With Armor and Bldg. Within 50 ft.

Parcel With Armor and Bldg. 50 ft. to100 ft.

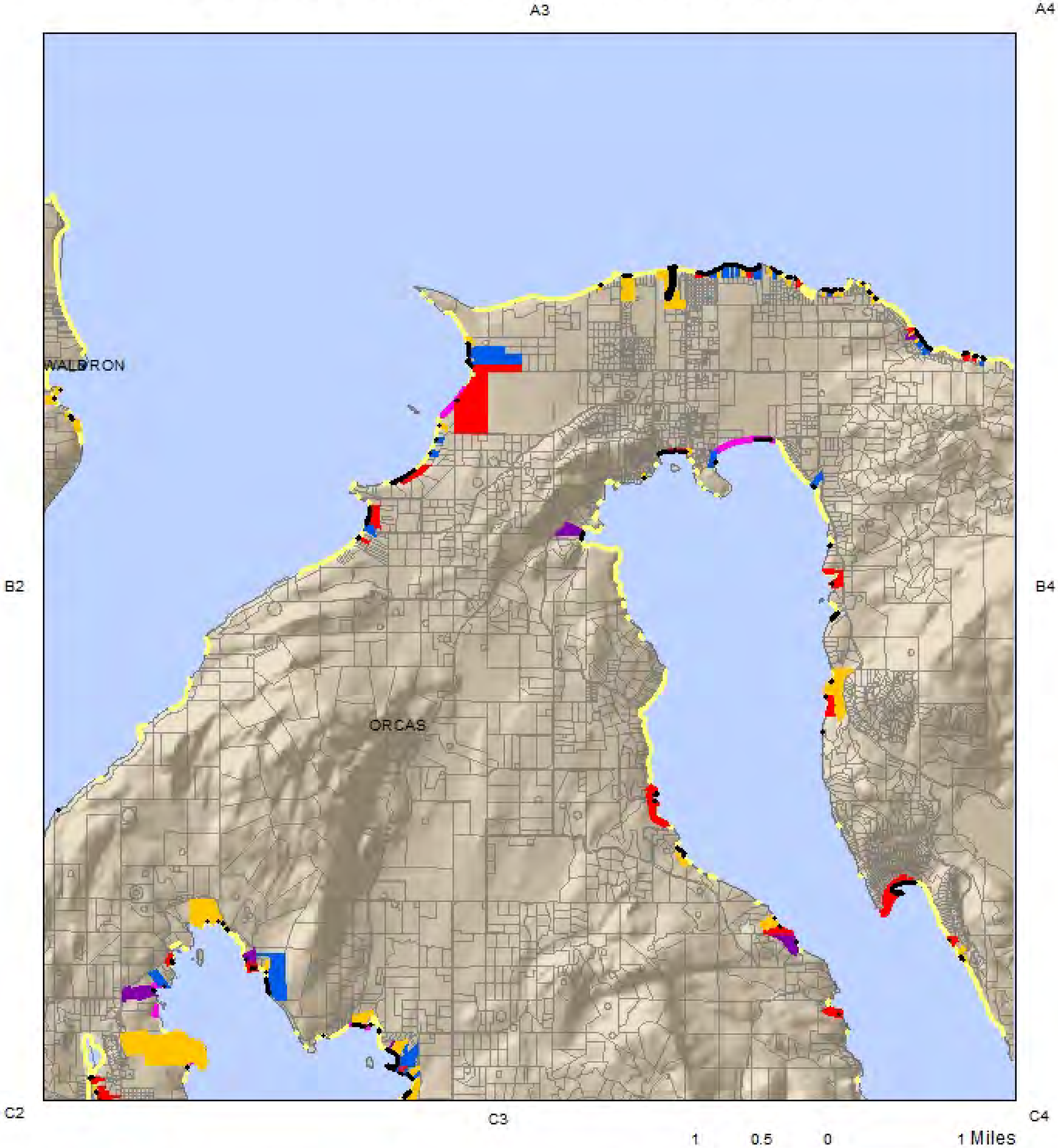
Parcel With Armor and Bldg. 100 ft. to 200 ft.

Parcel With Armor and Bldg. 200 ft. to 500 ft.



B2

Parcels With Armor And Building Setback



Legend (data shown for parcels with armor and structure only)

ARMOR

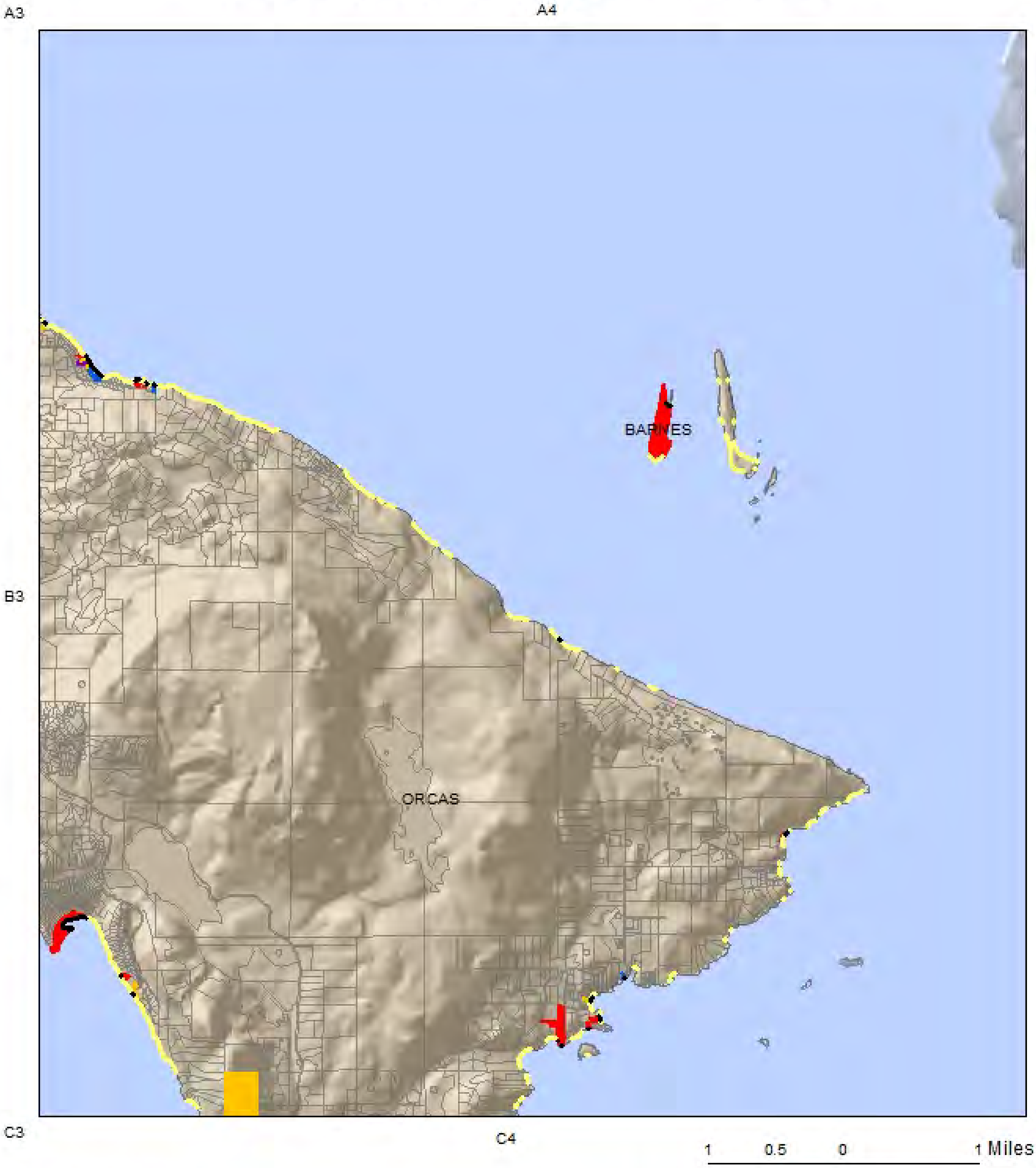
Documented Forage Fish Habitat — Potential Forage Fish Habitat

BUILDING DISTANCE FROM SHORELINE

- Parcel With Bldg. Within 50 ft.
- Parcel With Bldg. 50 ft. to100 ft.
- Parcel With Bldg. 100 ft. to 200 ft.
- Parcel With Bldg. 200 ft. to 500 ft.

B3

Parcels With Armor And Building Setback



Legend (data shown for parcels with armor and structure only)

ARMOR

Documented Forage Fish Habitat

Potential Forage Fish Habitat

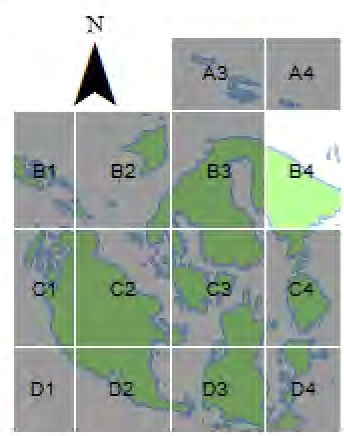
BUILDING DISTANCE FROM SHORELINE

Parcel With Armor and Bldg. Within 50 ft.

Parcel With Armor and Bldg. 50 ft. to100 ft.

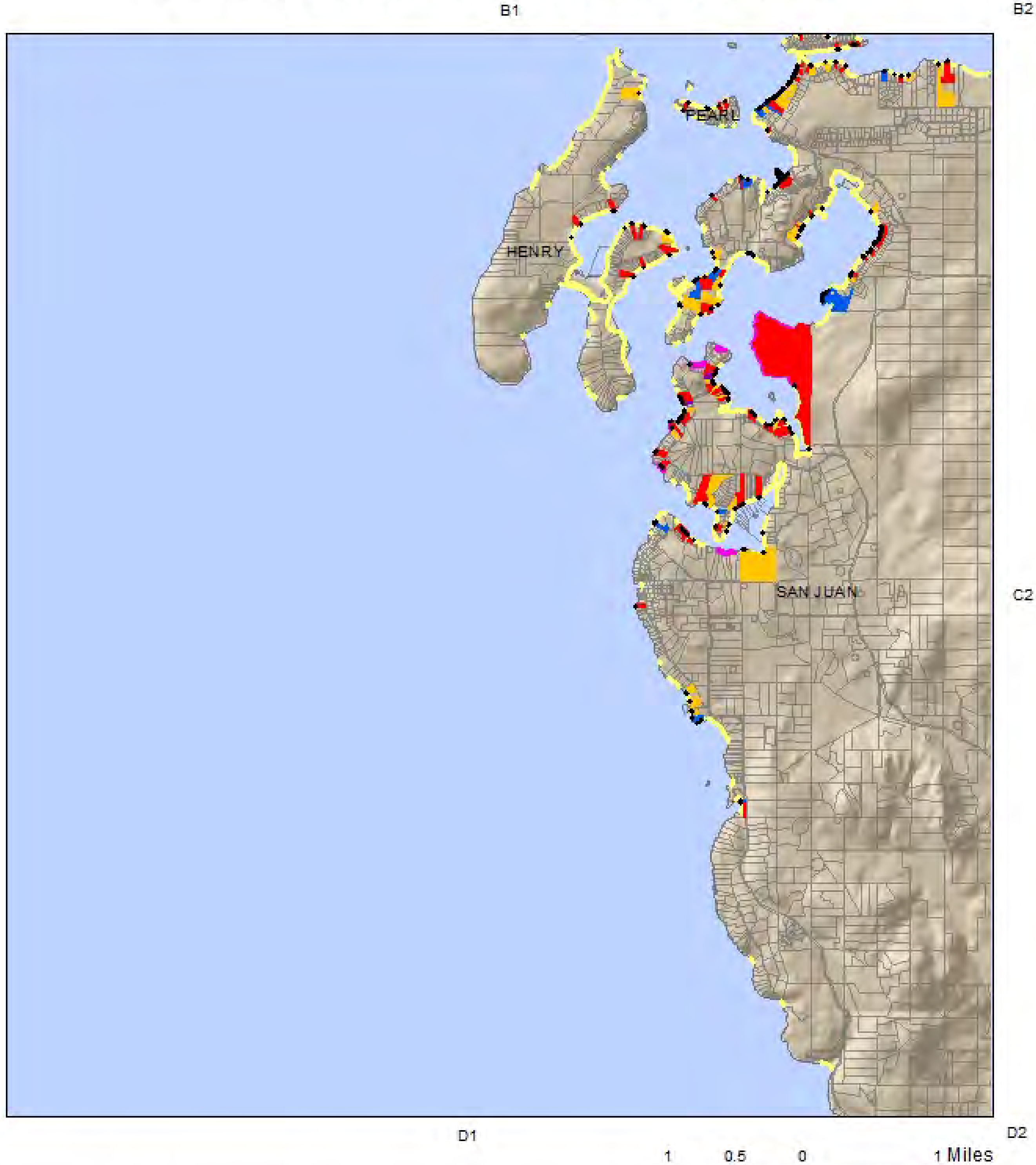
Parcel With Armor and Bldg. 100 ft. to 200 ft.

Parcel With Armor and Bldg. 200 ft. to 500 ft.



B4

Parcels With Armor And Building Setback



Legend (data shown for parcels with armor and structure only)

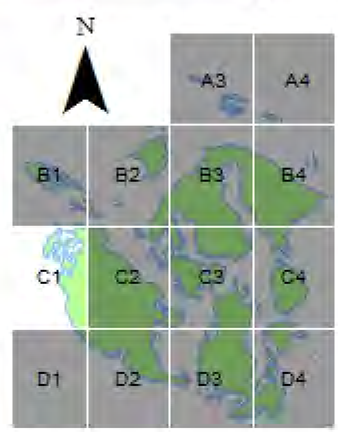
ARMOR

Documented Forage Fish Habitat

Potential Forage Fish Habitat

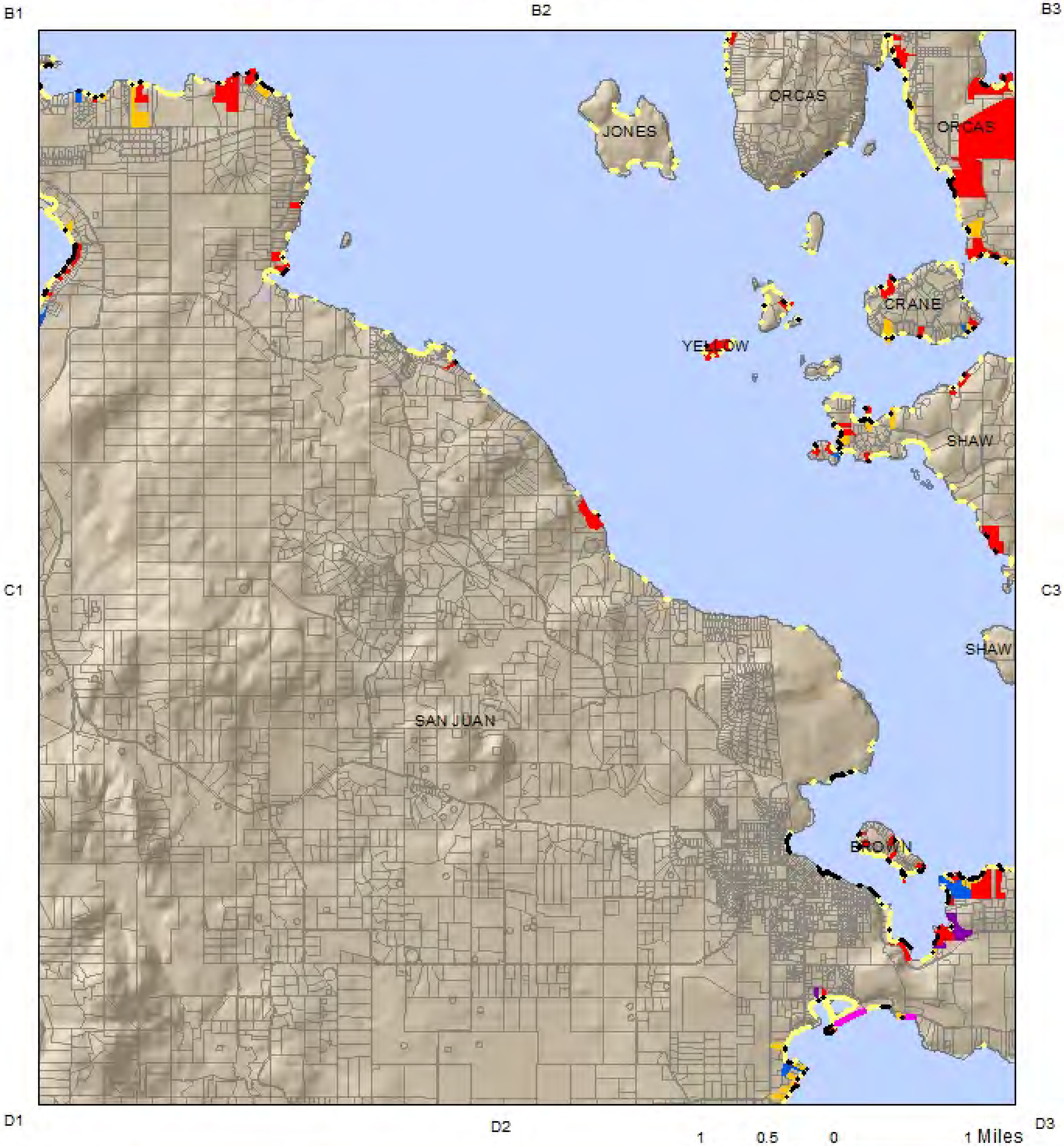
BUILDING DISTANCE FROM SHORELINE

- Parcel With Bldg. Within 50 ft.
- Parcel With Bldg. 50 ft. to100 ft.
- Parcel With Bldg. 100 ft. to 200 ft.
- Parcel With Bldg. 200 ft. to 500 ft.



C1

Parcels With Armor And Building Setback



Legend (data shown for parcels with armor and structure only)

ARMOR

Documented Forage Fish Habitat

Potential Forage Fish Habitat

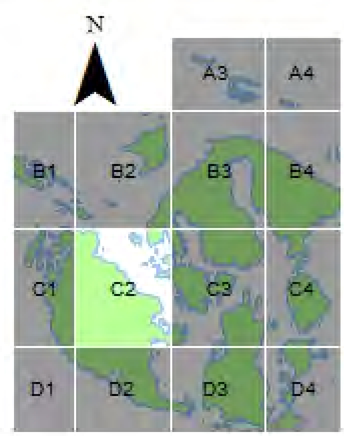
BUILDING DISTANCE FROM SHORELINE

Parcel With Armor and Bldg. Within 50 ft.

Parcel With Armor and Bldg. 50 ft. to100 ft.

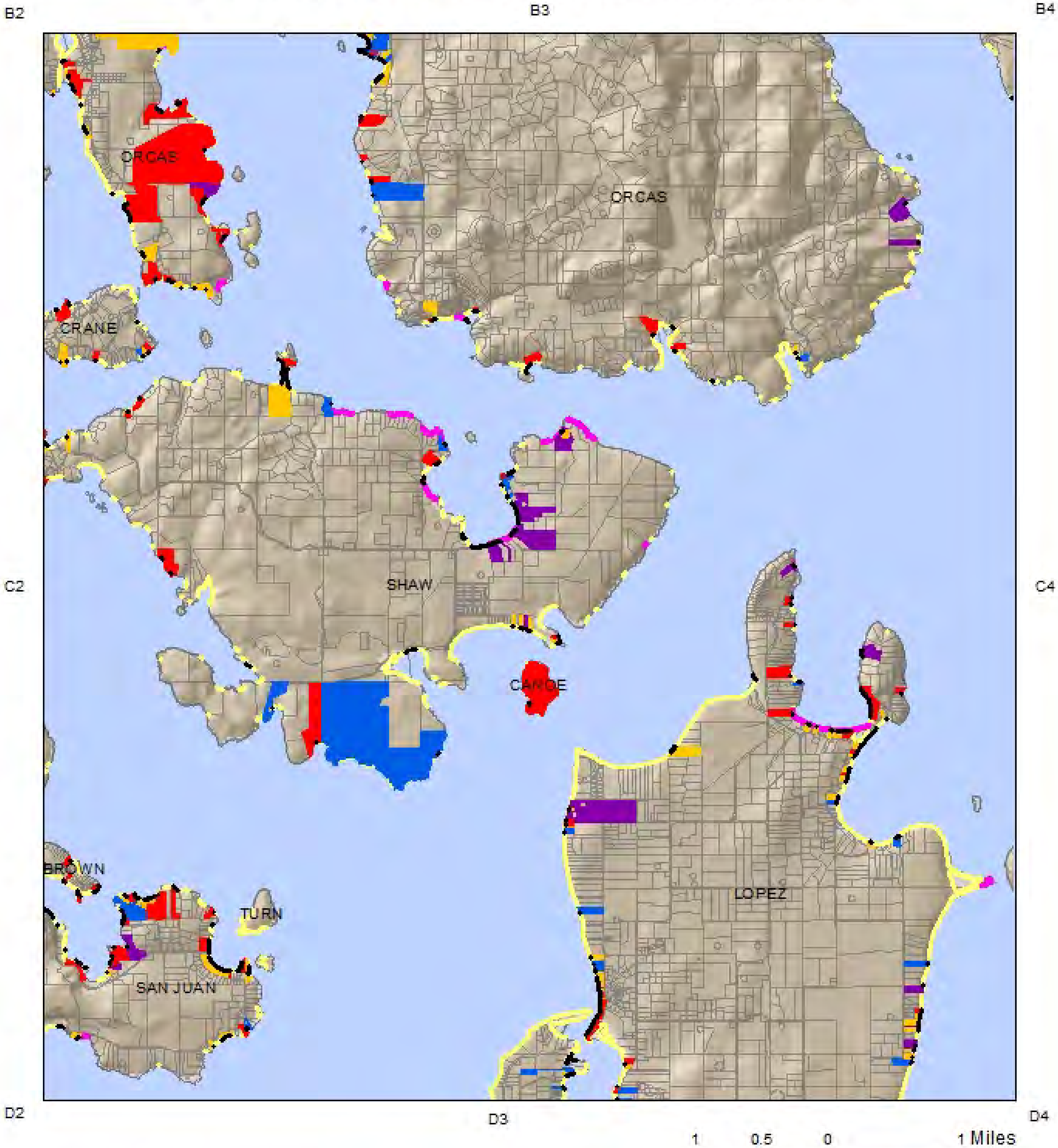
Parcel With Armor and Bldg. 100 ft. to 200 ft.

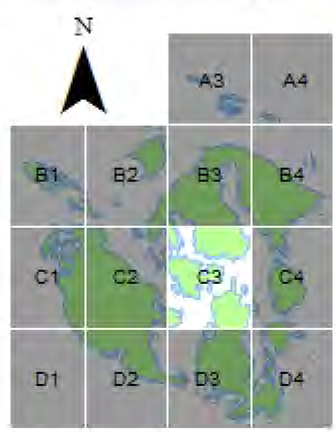
Parcel With Armor and Bldg. 200 ft. to 500 ft.



C2

Parcels With Armor And Building Setback





Legend (data shown for parcels with armor and structure only)

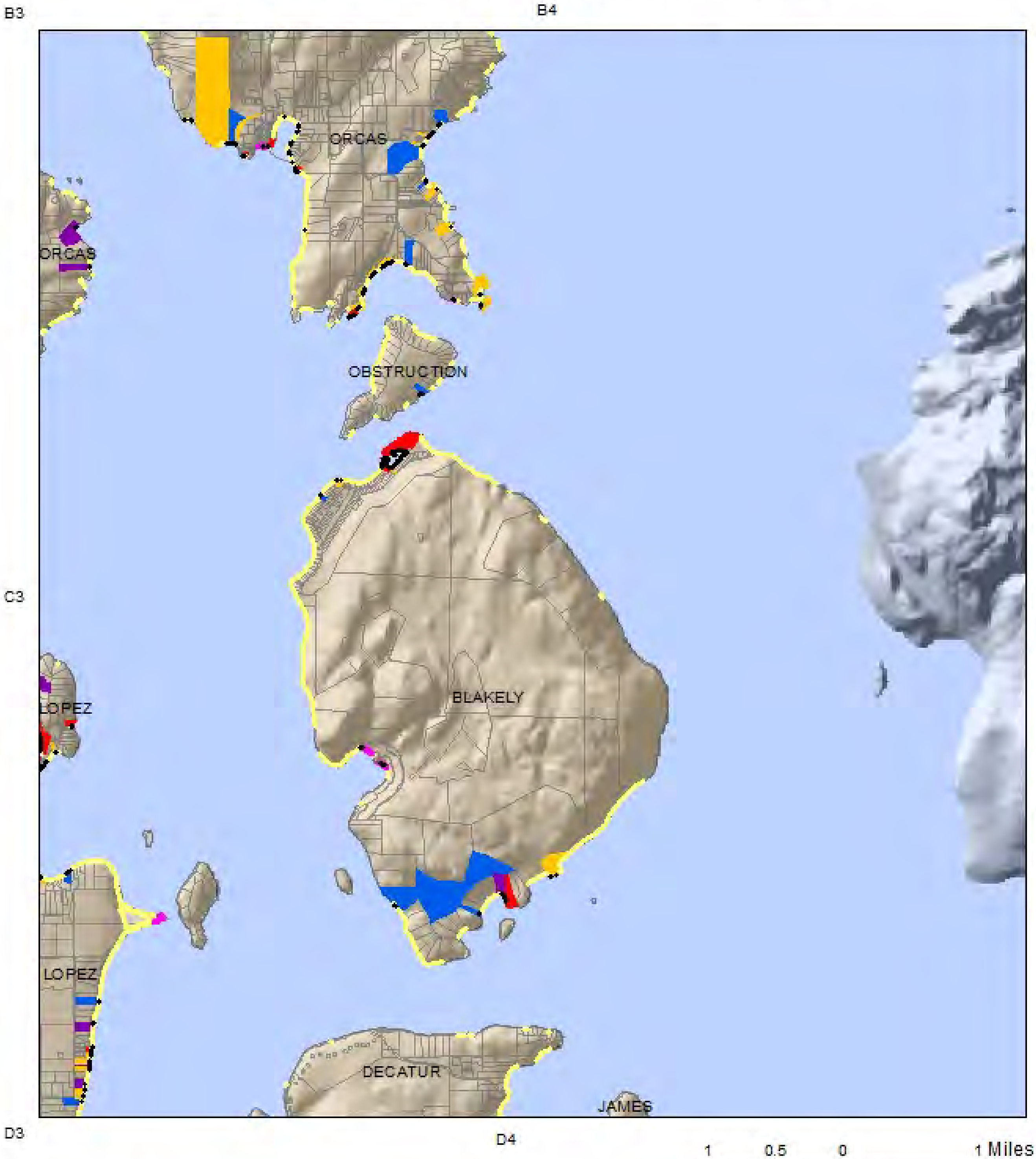
- ARMOR
- Documented Forage Fish Habitat
- Potential Forage Fish Habitat

BUILDING DISTANCE FROM SHORELINE

- Parcel With Bldg. Within 50 ft.
- Parcel With Bldg. 50 ft. to100 ft.
- Parcel With Bldg. 100 ft. to 200 ft.
- Parcel With Bldg. 200 ft. to 500 ft.

C3

Parcels With Armor And Building Setback

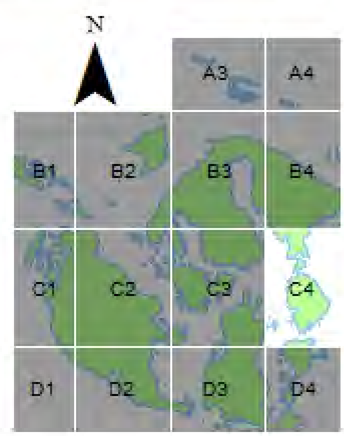


Legend (data shown for parcels with armor and structure only)

- ARMOR
- Documented Forage Fish Habitat
- Potential Forage Fish Habitat

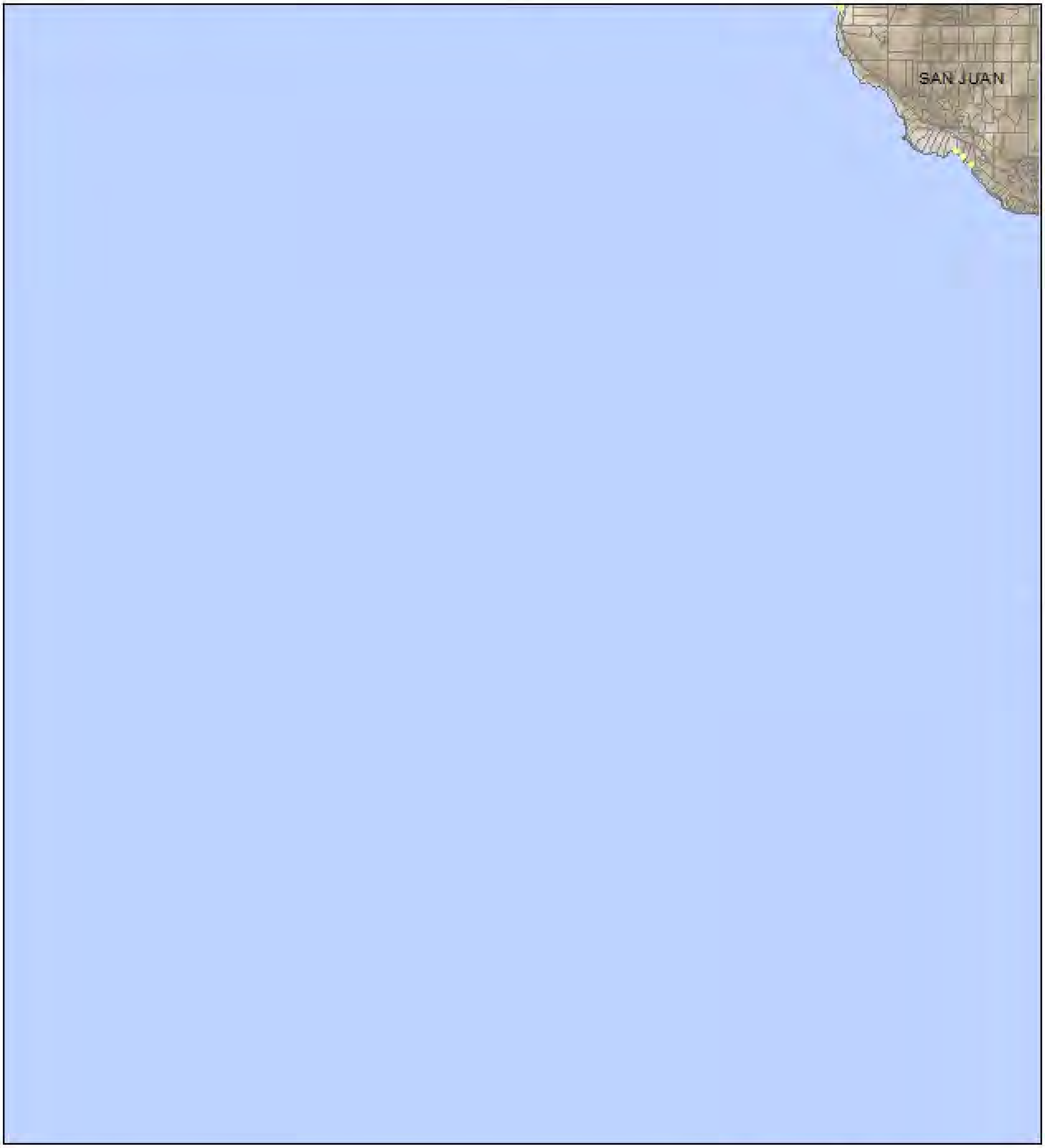
BUILDING DISTANCE FROM SHORELINE

- Parcel With Armor and Bldg. Within 50 ft.
- Parcel With Armor and Bldg. 50 ft. to100 ft.
- Parcel With Armor and Bldg. 100 ft. to 200 ft.
- Parcel With Armor and Bldg. 200 ft. to 500 ft.



C4

Parcels With Armor And Building Setback



1 0.5 0 1 Miles

Legend (data shown for parcels with armor and structure only)

ARMOR

Documented Forage Fish Habitat

Potential Forage Fish Habitat

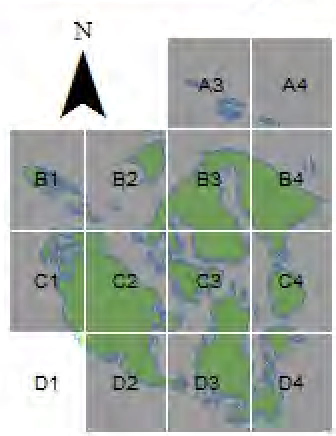
BUILDING DISTANCE FROM SHORELINE

Parcel With Bldg. Within 50 ft.

Parcel With Bldg. 50 ft. to100 ft.

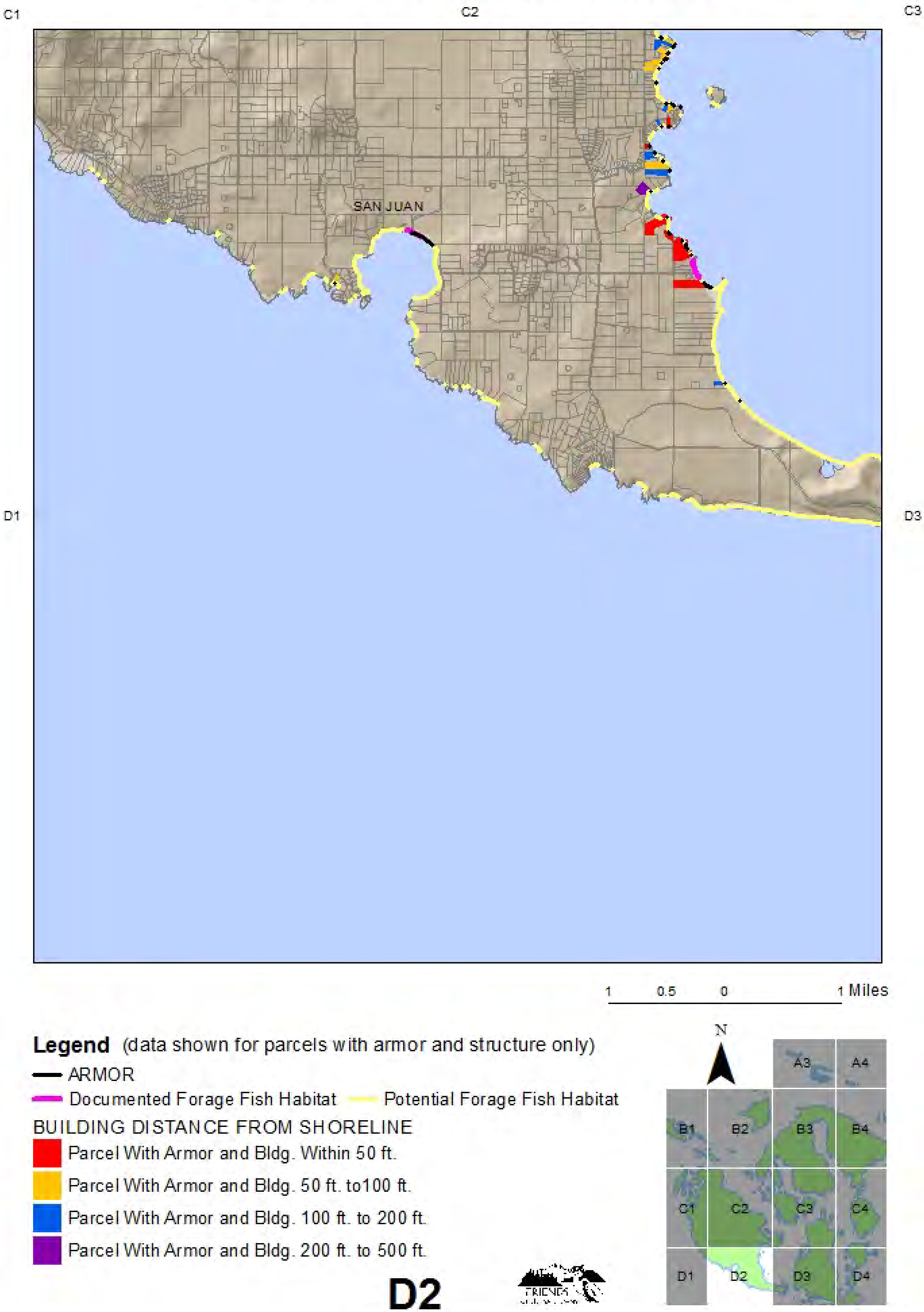
Parcel With Bldg. 100 ft. to 200 ft.

Parcel With Bldg. 200 ft. to 500 ft.



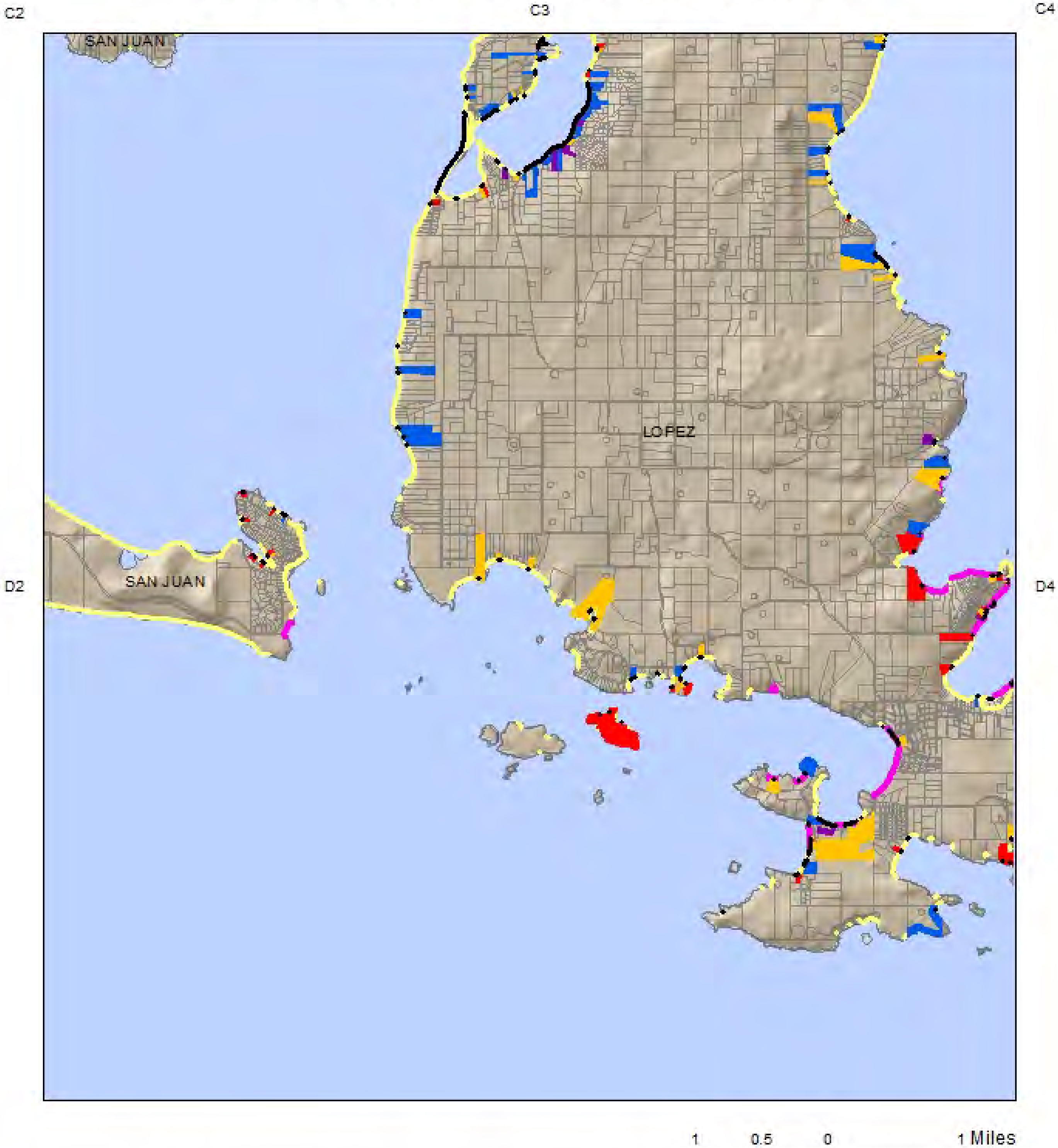
D1

Parcels With Armor And Building Setback



D2

Parcels With Armor And Building Setback

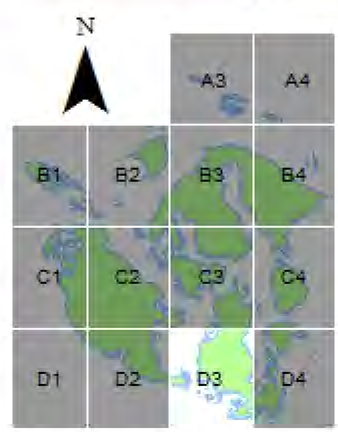


Legend (data shown for parcels with armor and structure only)

- ARMOR
- Documented Forage Fish Habitat
- Potential Forage Fish Habitat

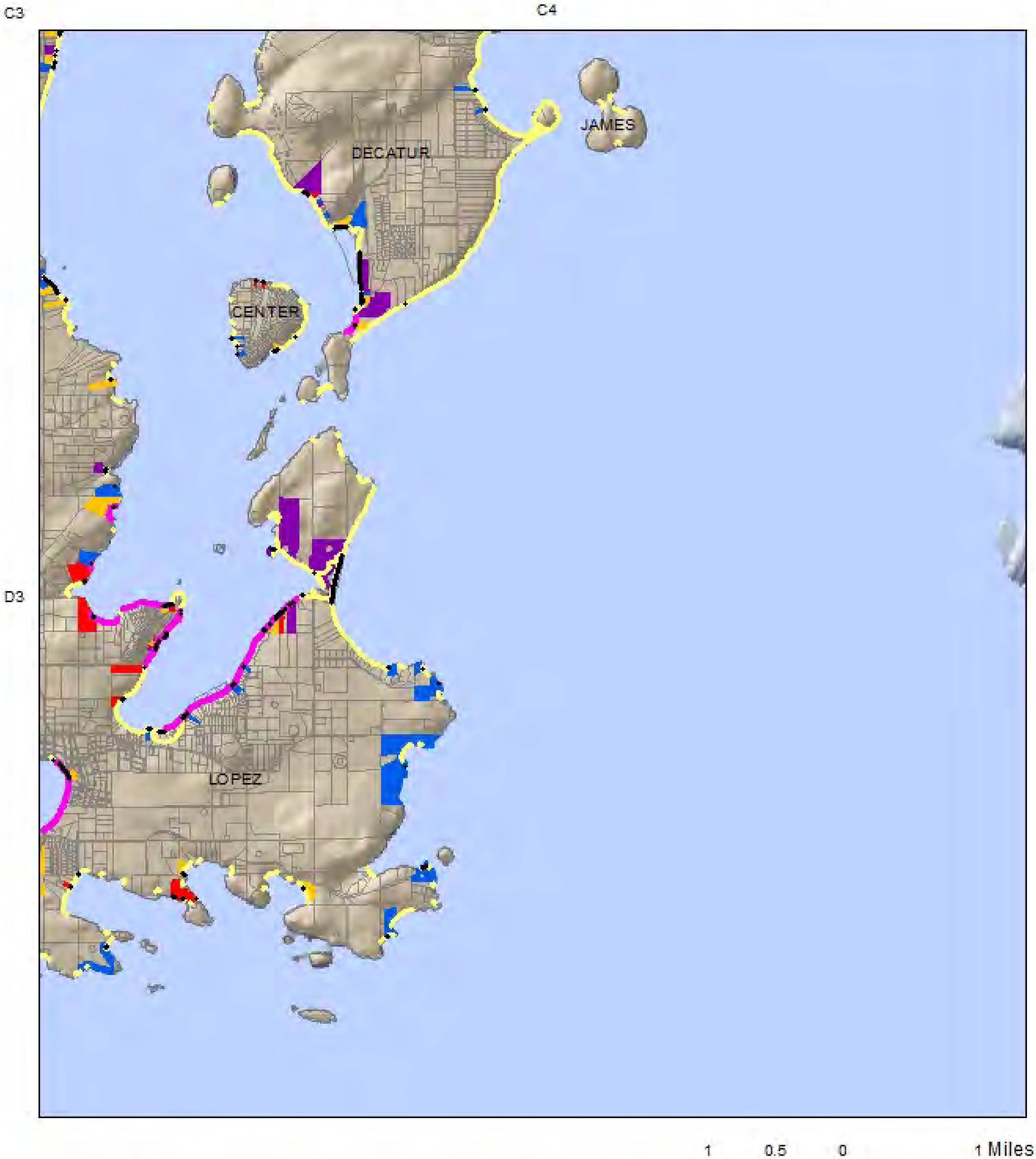
BUILDING DISTANCE FROM SHORELINE

- Parcel With Bldg. Within 50 ft.
- Parcel With Bldg. 50 ft. to100 ft.
- Parcel With Bldg. 100 ft. to 200 ft.
- Parcel With Bldg. 200 ft. to 500 ft.



D3

Parcels With Armor And Building Setback

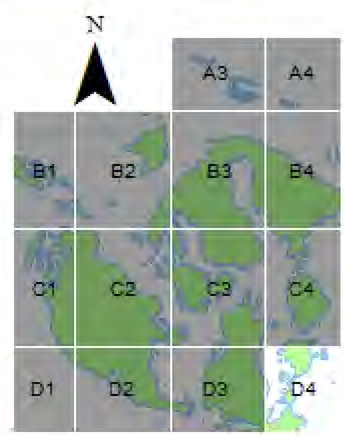


Legend (data shown for parcels with armor and structure only)

ARMOR
Documented Forage Fish Habitat
Potential Forage Fish Habitat

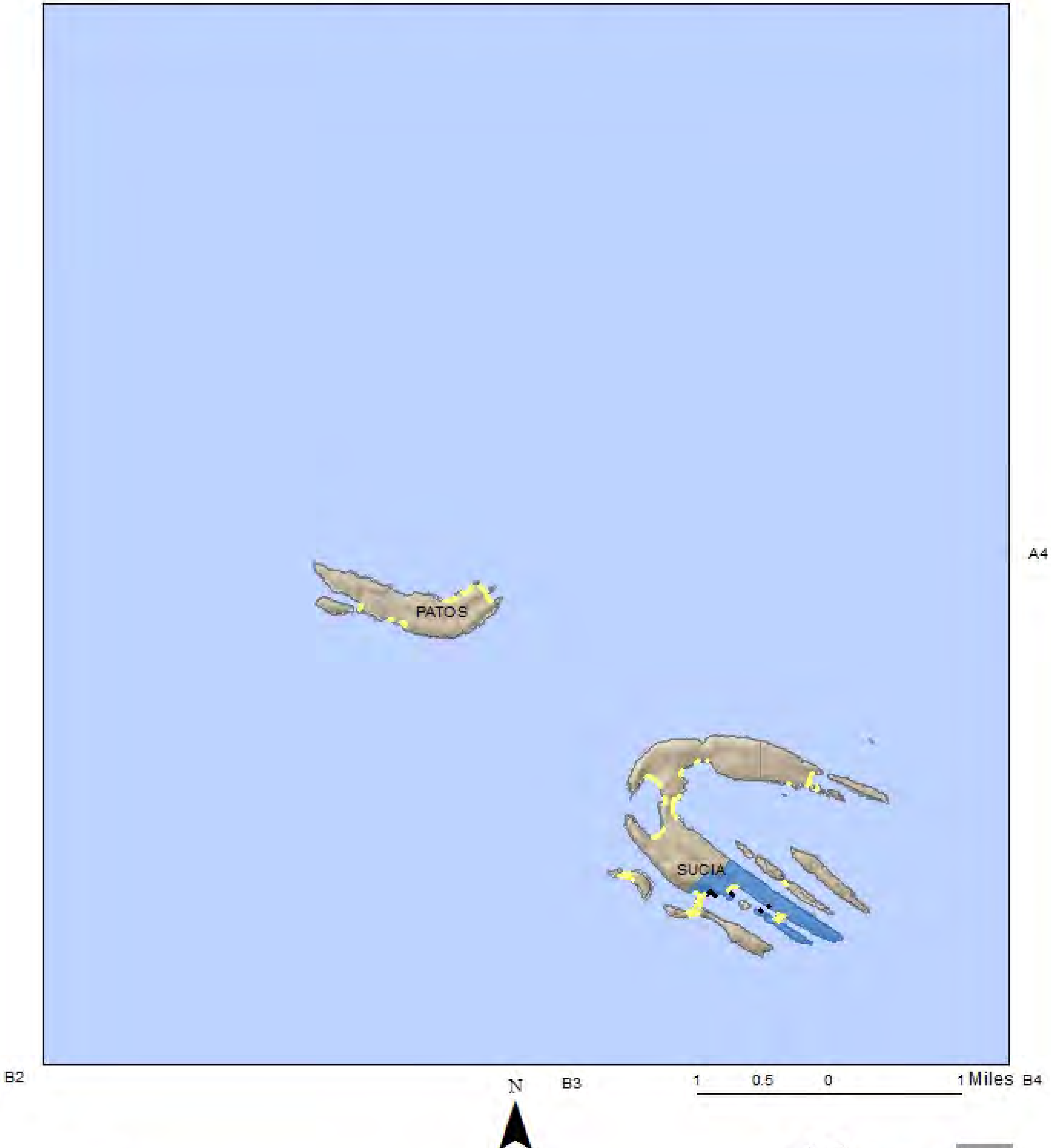
BUILDING DISTANCE FROM SHORELINE

- Parcel With Armor and Bldg. Within 50 ft.
- Parcel With Armor and Bldg. 50 ft. to100 ft.
- Parcel With Armor and Bldg. 100 ft. to 200 ft.
- Parcel With Armor and Bldg. 200 ft. to 500 ft.



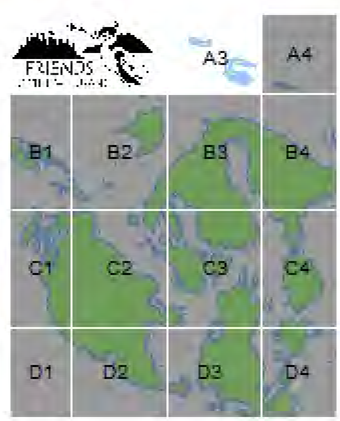
D4

Armor Impacts To Forage Fish Habitat



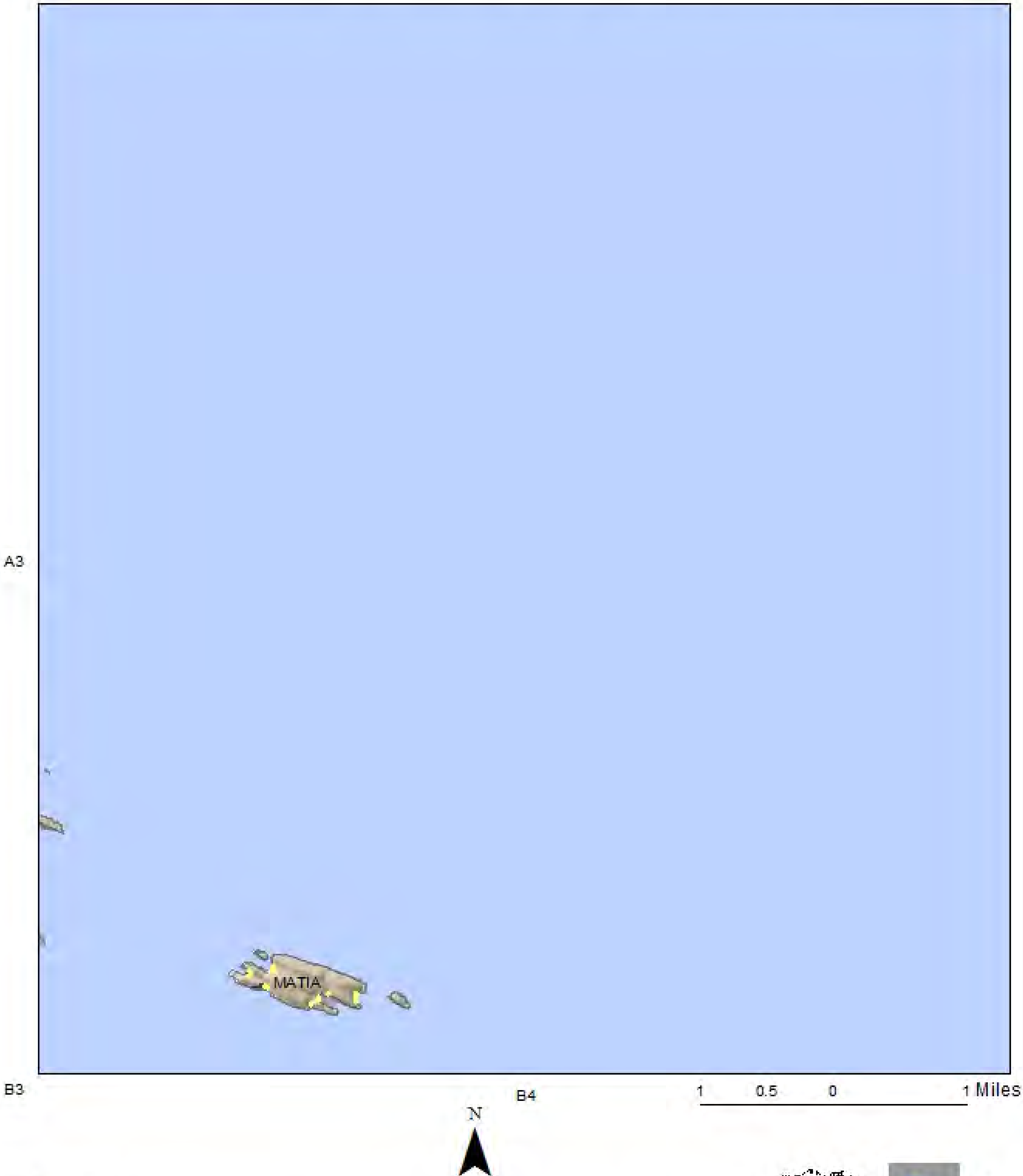
Legend

- Impact to Sediment Supply in Drift Cell With Documented Spawn
- Impact to Sediment Transport in Drift Cell With Documented Spawn
- Direct Burial of Documented Spawn Habitat
- Groin Impact to Sediment Transport in Drift Cell With Documented Spawn
- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- All Parcels with Armor



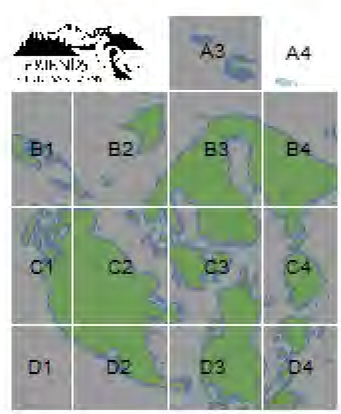
A3

Armor Impacts To Forage Fish Habitat



Legend
- Impact to Sediment Supply in Drift Cell With Documented Spawn
- Impact to Sediment Transport in Drift Cell With Documented Spawn
- Direct Burial of Documented Spawn Habitat
- Groin Impact to Sediment Transport in Drift Cell With Documented Spawn
- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- All Parcels with Armor

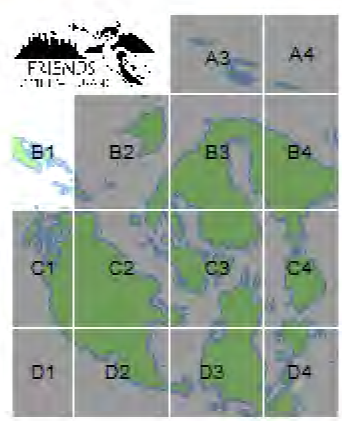
A4



Armor Impacts To Forage Fish Habitat

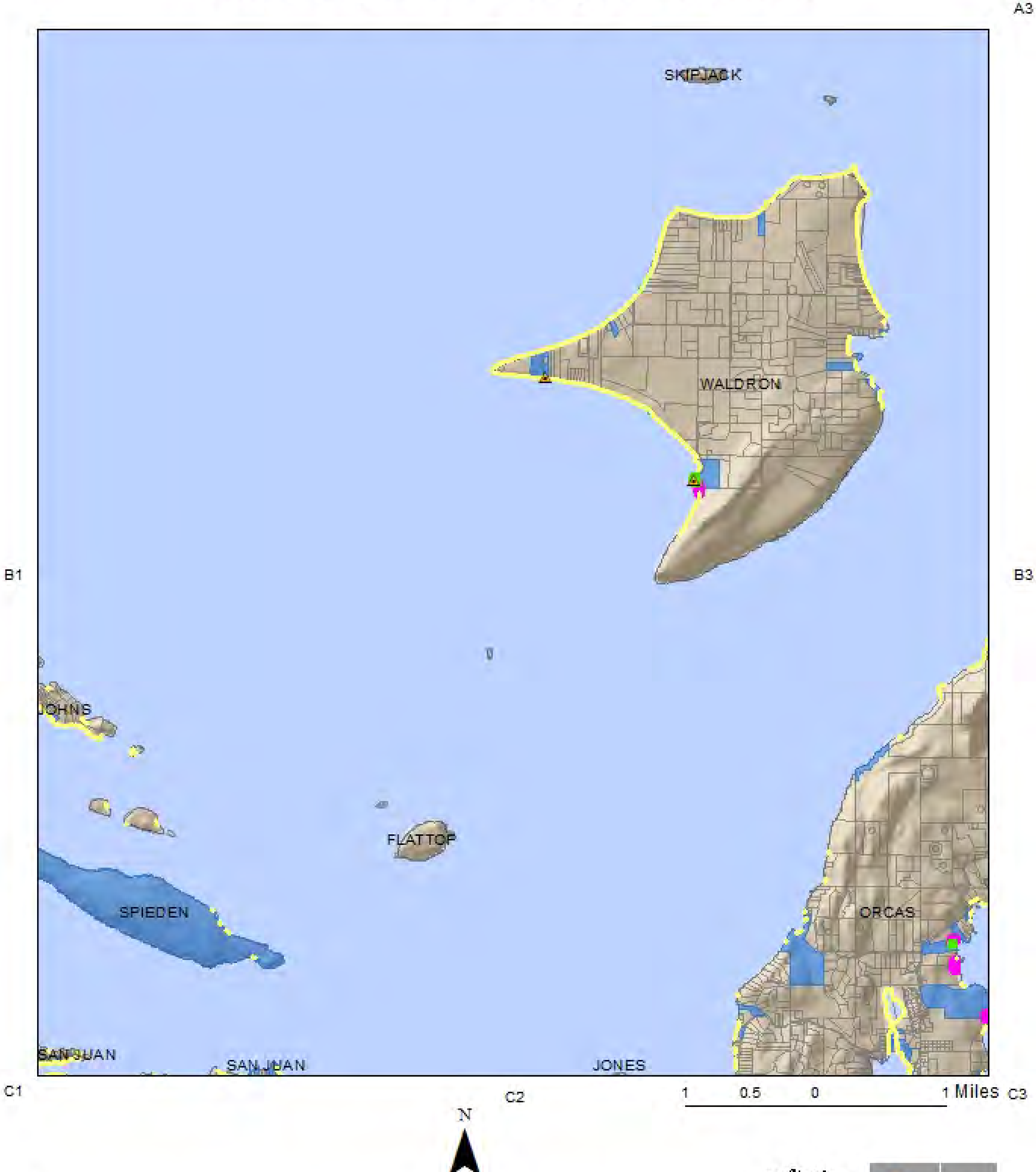
Legend

- Impact to Sediment Supply in Drift Cell With Documented Spawn
- Impact to Sediment Transport in Drift Cell With Documented Spawn
- Direct Burial of Documented Spawn Habitat
- Groin Impact to Sediment Transport in Drift Cell With Documented Spawn
- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- All Parcels with Armor



B1

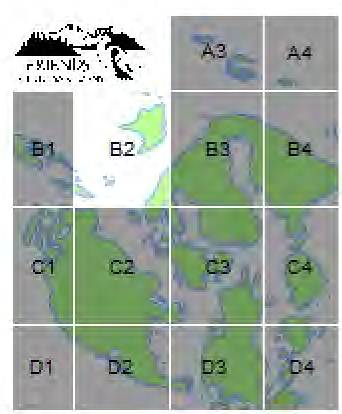
Armor Impacts To Forage Fish Habitat



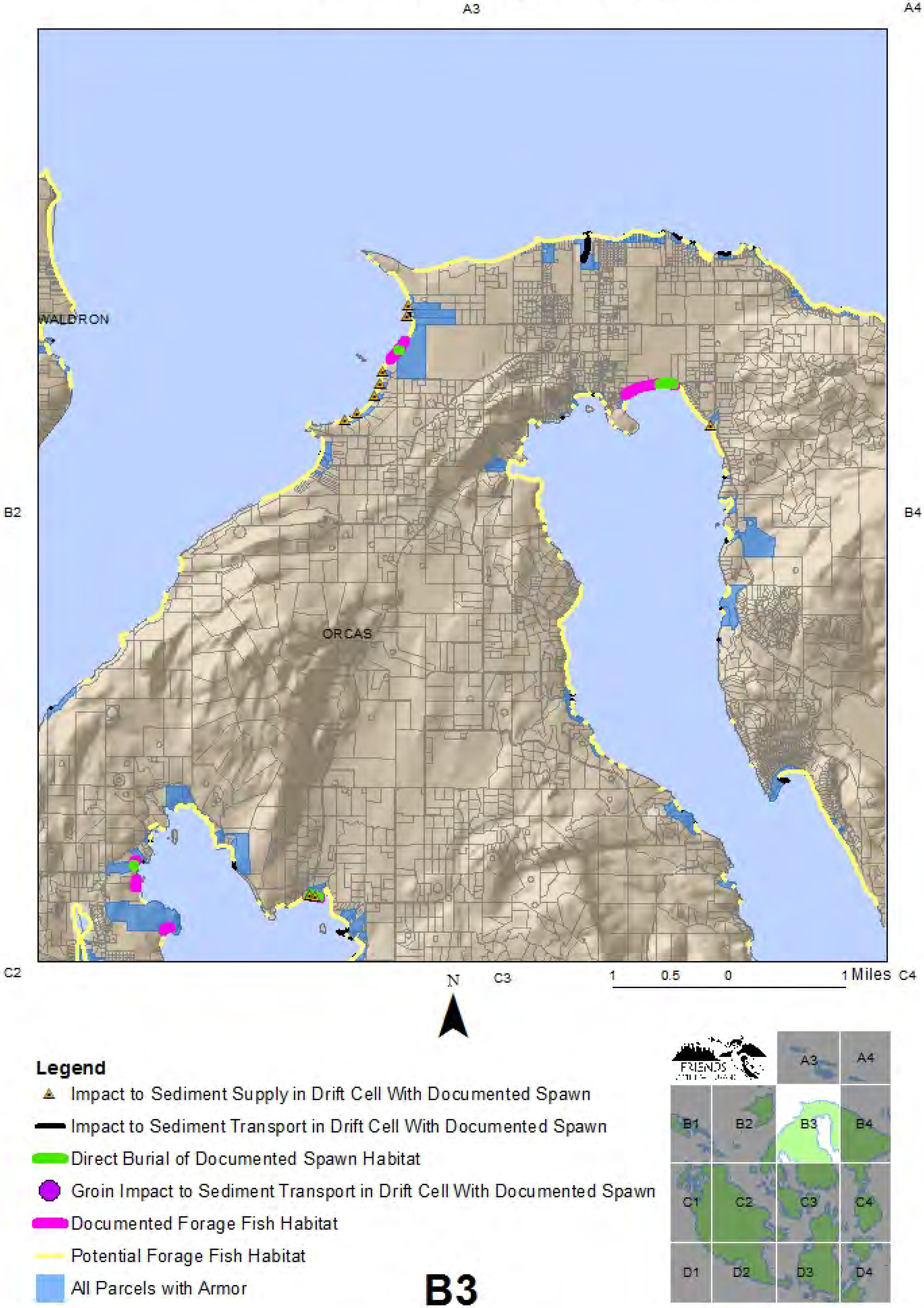
Legend

- Impact to Sediment Supply in Drift Cell With Documented Spawn
- Impact to Sediment Transport in Drift Cell With Documented Spawn
- Direct Burial of Documented Spawn Habitat
- Groin Impact to Sediment Transport in Drift Cell With Documented Spawn
- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- All Parcels with Armor

B2



Armor Impacts To Forage Fish Habitat

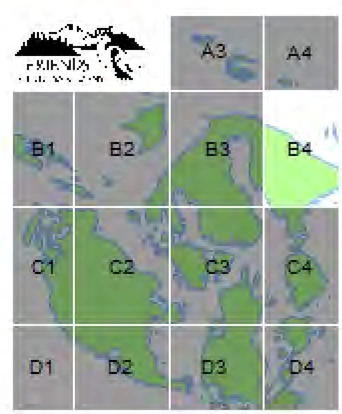


Armor Impacts To Forage Fish Habitat

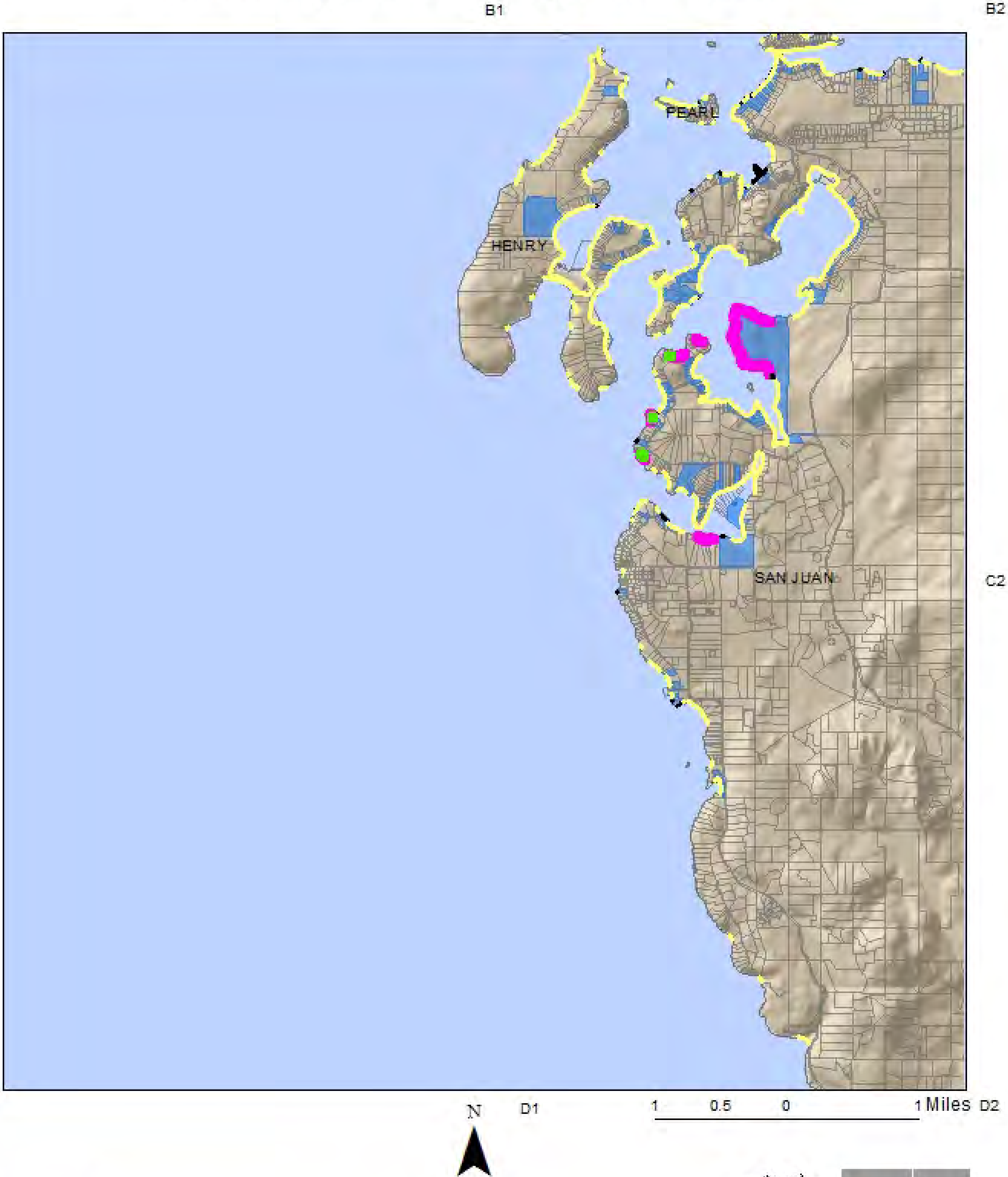
Legend

- Impact to Sediment Supply in Drift Cell With Documented Spawn
- Impact to Sediment Transport in Drift Cell With Documented Spawn
- Direct Burial of Documented Spawn Habitat
- Groin Impact to Sediment Transport in Drift Cell With Documented Spawn
- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- All Parcels with Armor

B4

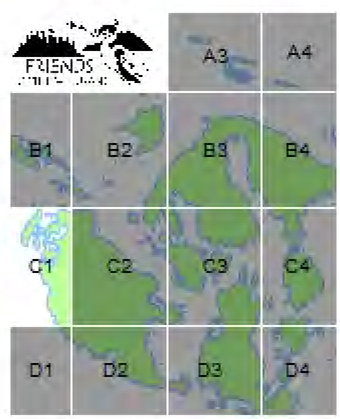


Armor Impacts To Forage Fish Habitat



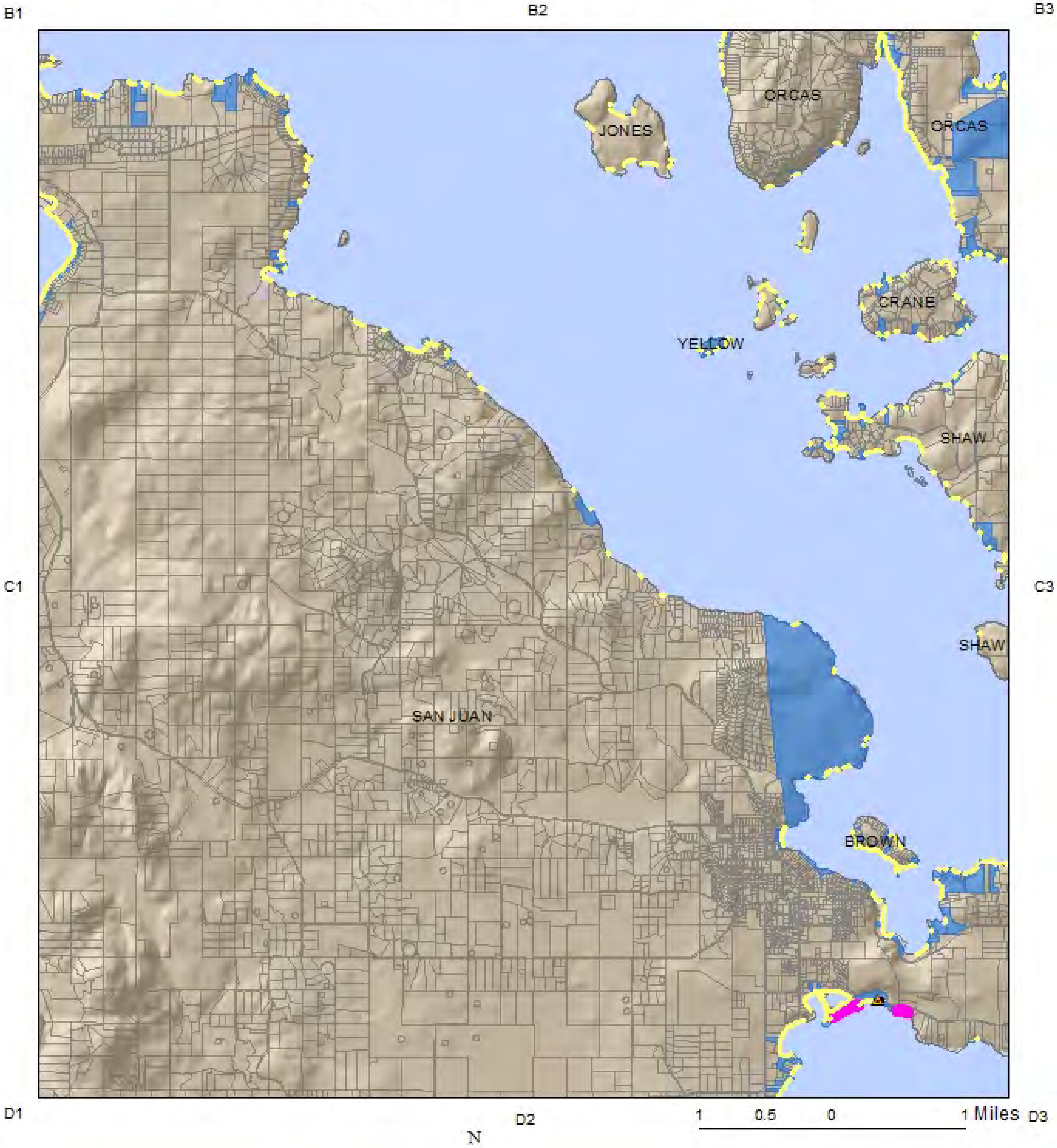
Legend

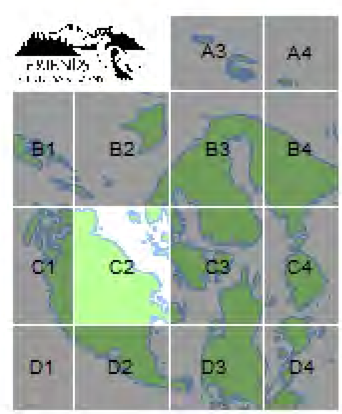
- Impact to Sediment Supply in Drift Cell With Documented Spawn
- Impact to Sediment Transport in Drift Cell With Documented Spawn
- Direct Burial of Documented Spawn Habitat
- Groin Impact to Sediment Transport in Drift Cell With Documented Spawn
- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- All Parcels with Armor



C1

Armor Impacts To Forage Fish Habitat



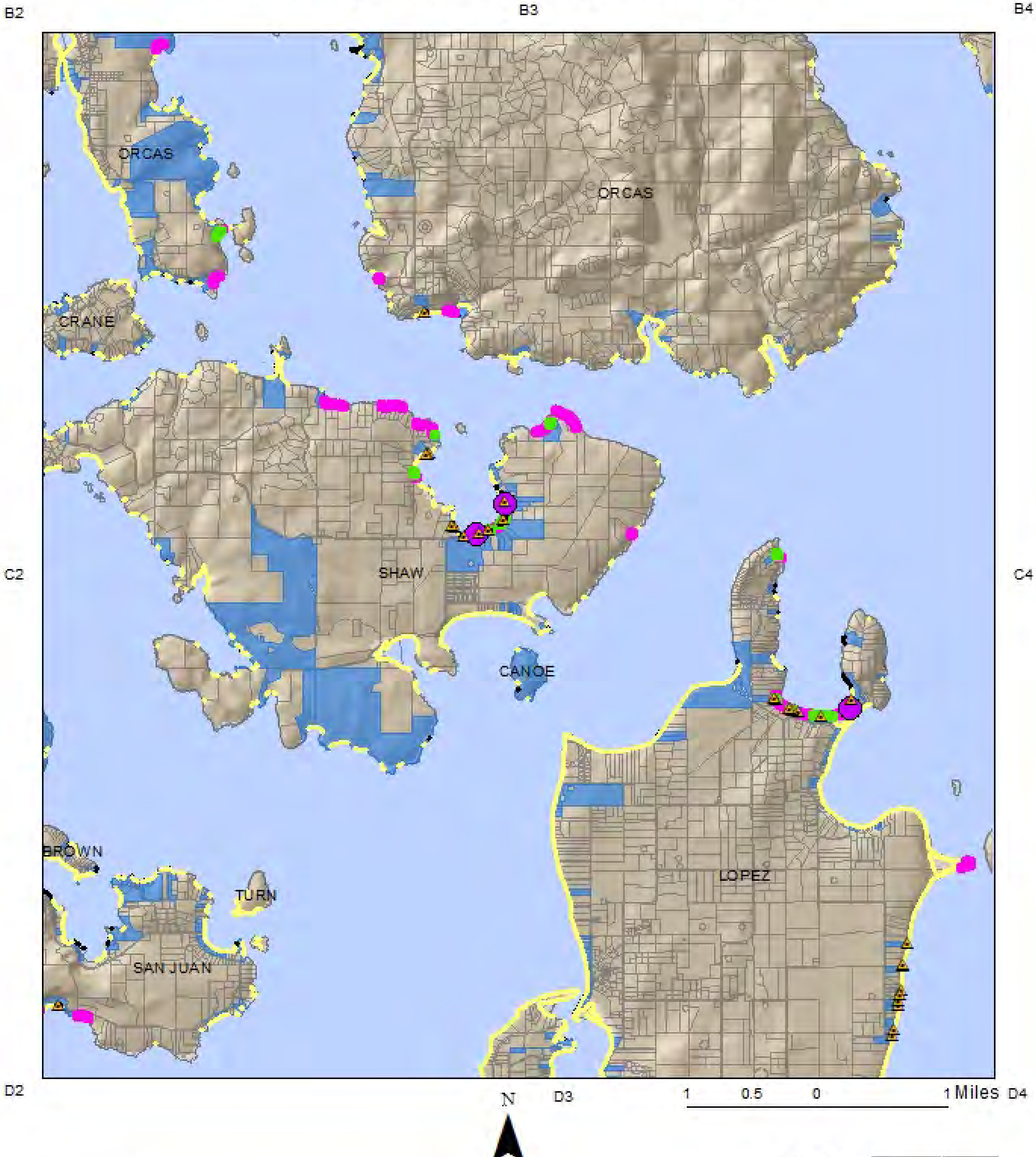


Legend

- Impact to Sediment Supply in Drift Cell With Documented Spawn
- Impact to Sediment Transport in Drift Cell With Documented Spawn
- Direct Burial of Documented Spawn Habitat
- Groin Impact to Sediment Transport in Drift Cell With Documented Spawn
- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- All Parcels with Armor

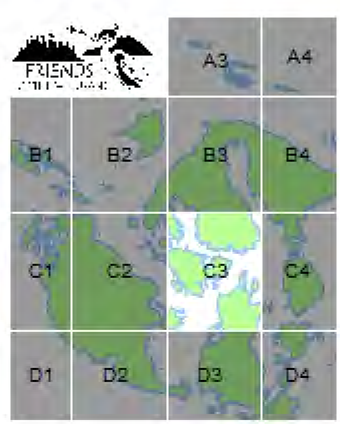
C2

Armor Impacts To Forage Fish Habitat



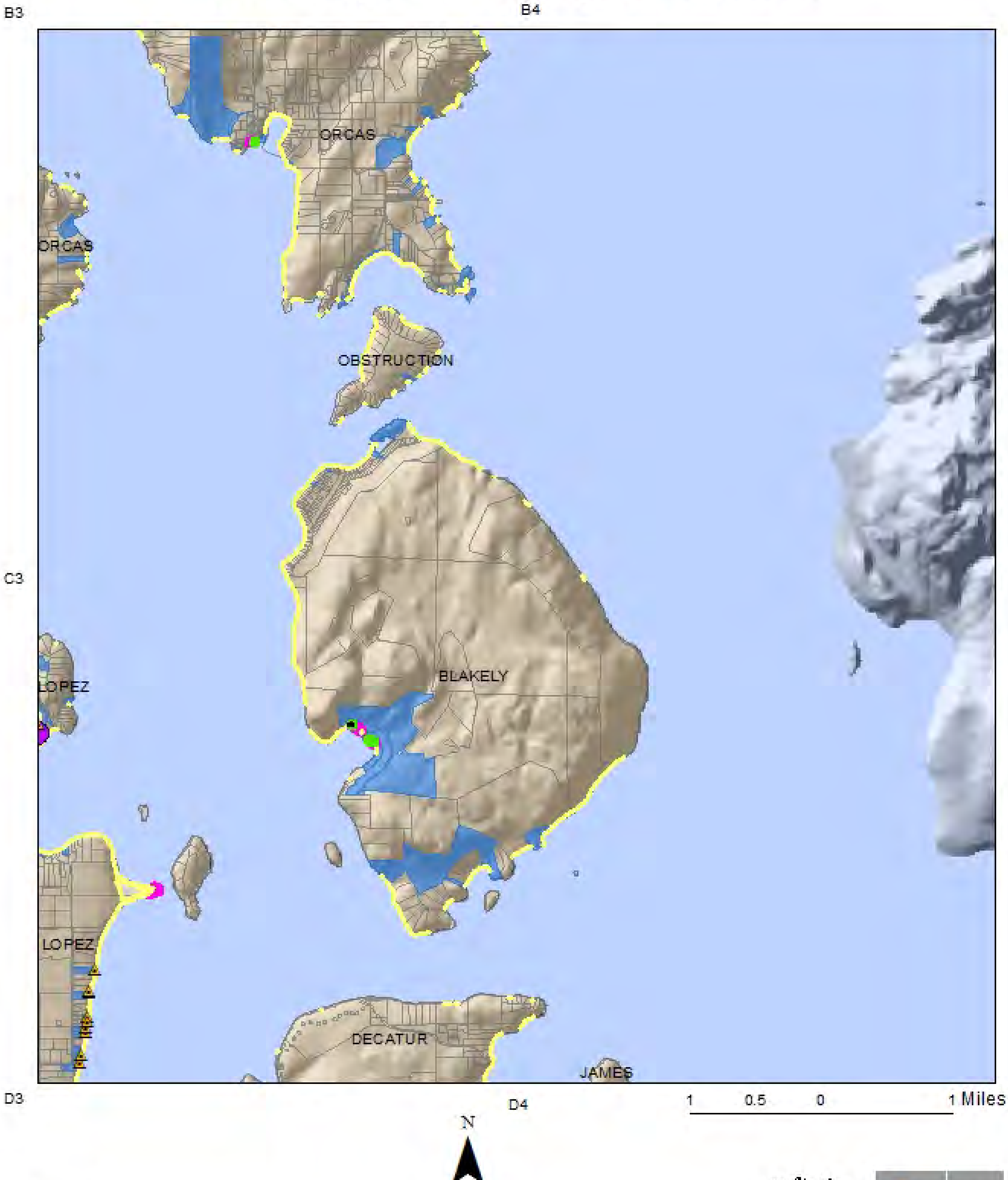
Legend

- Impact to Sediment Supply in Drift Cell With Documented Spawn
- Impact to Sediment Transport in Drift Cell With Documented Spawn
- Direct Burial of Documented Spawn Habitat
- Groin Impact to Sediment Transport in Drift Cell With Documented Spawn
- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- All Parcels with Armor



C3

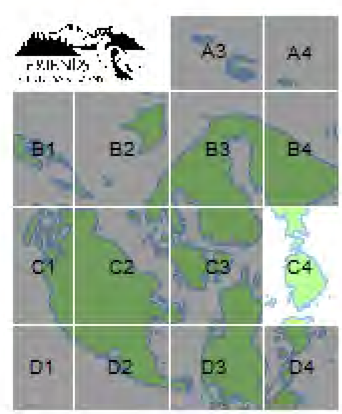
Armor Impacts To Forage Fish Habitat



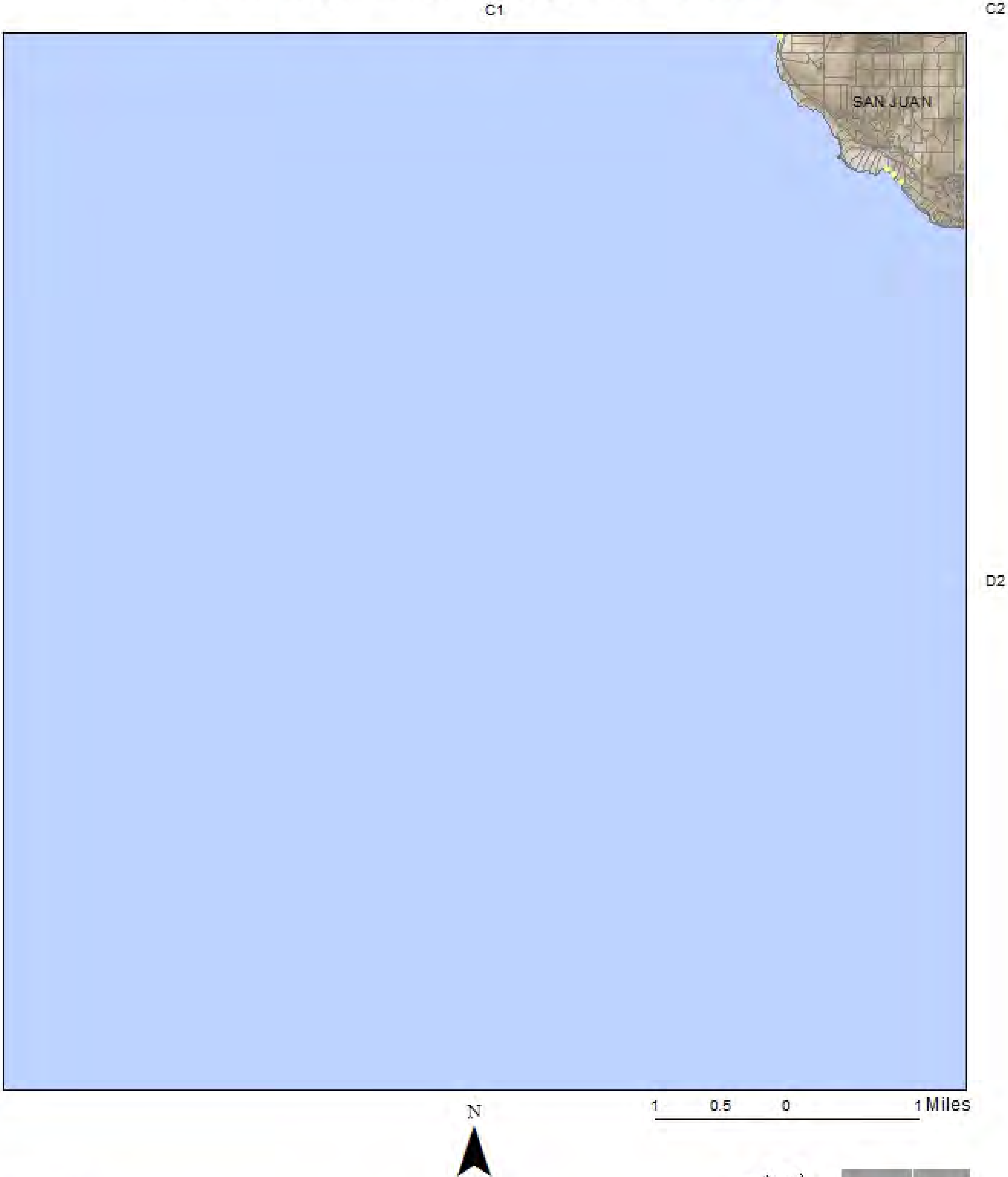
Legend

- Impact to Sediment Supply in Drift Cell With Documented Spawn
- Impact to Sediment Transport in Drift Cell With Documented Spawn
- Direct Burial of Documented Spawn Habitat
- Groin Impact to Sediment Transport in Drift Cell With Documented Spawn
- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- All Parcels with Armor

C4

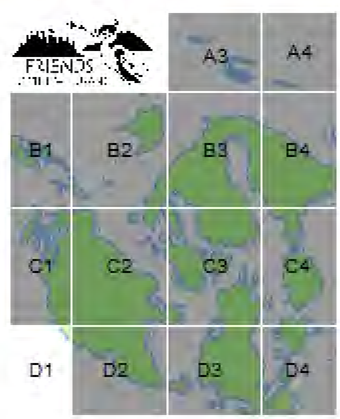


Armor Impacts To Forage Fish Habitat



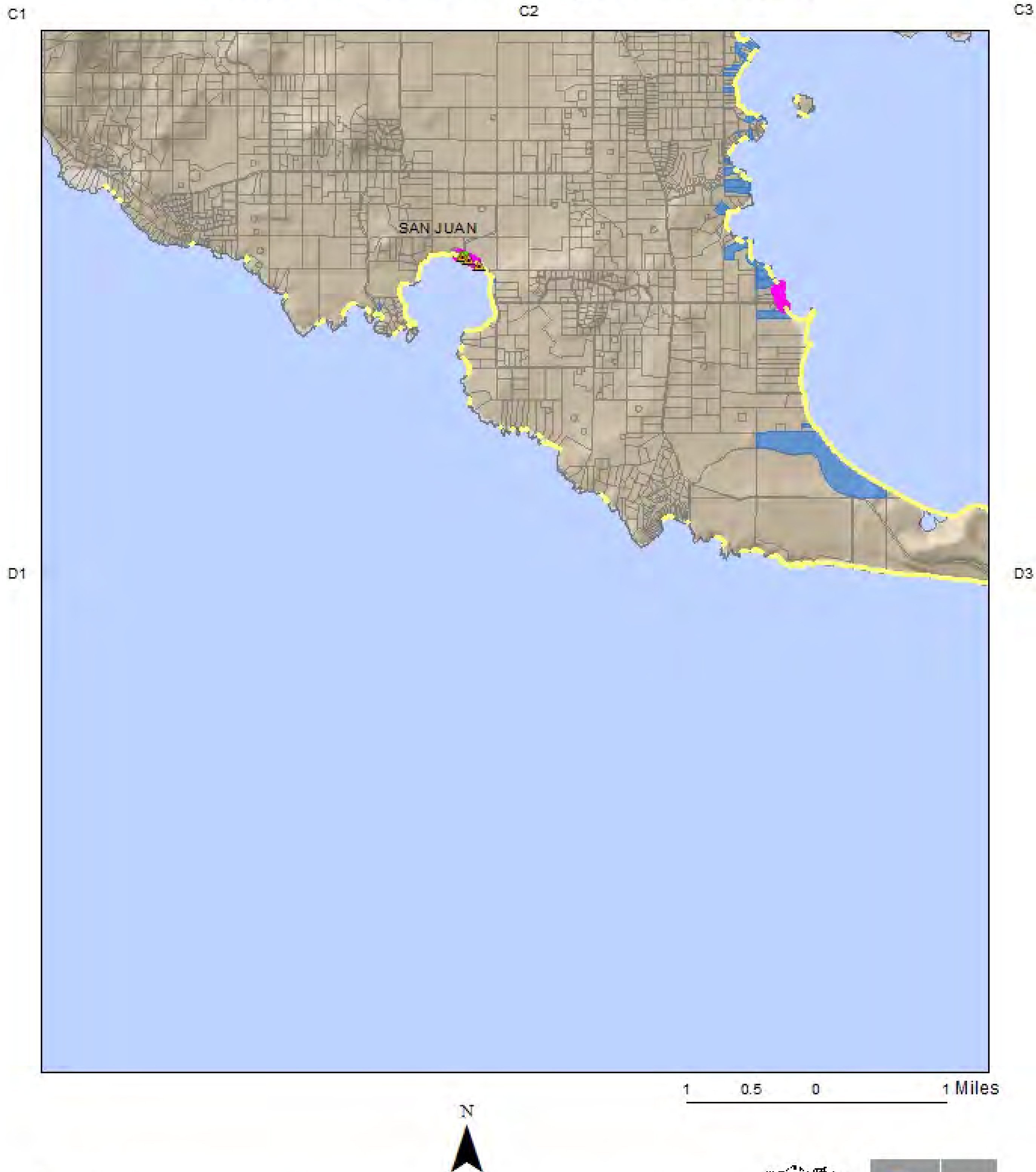
Legend

- Impact to Sediment Supply in Drift Cell With Documented Spawn
- Impact to Sediment Transport in Drift Cell With Documented Spawn
- Direct Burial of Documented Spawn Habitat
- Groin Impact to Sediment Transport in Drift Cell With Documented Spawn
- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- All Parcels with Armor



D1

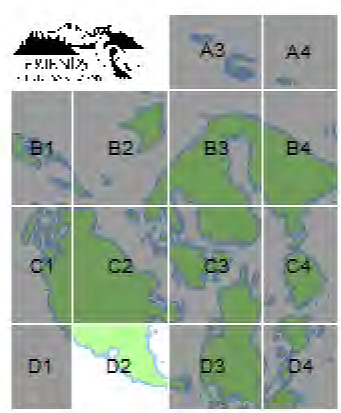
Armor Impacts To Forage Fish Habitat



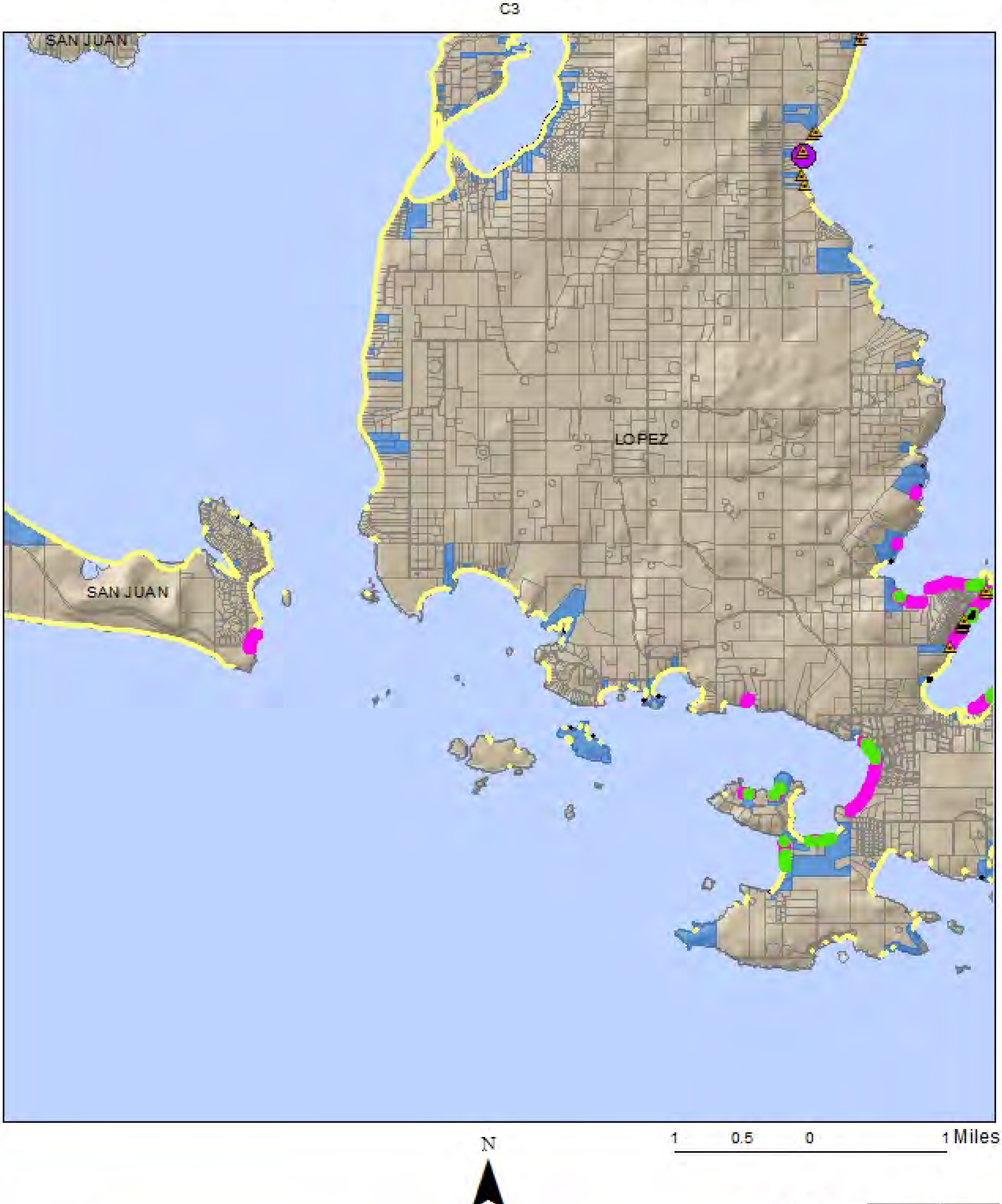
Legend

- Impact to Sediment Supply in Drift Cell With Documented Spawn
- Impact to Sediment Transport in Drift Cell With Documented Spawn
- Direct Burial of Documented Spawn Habitat
- Groin Impact to Sediment Transport in Drift Cell With Documented Spawn
- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- All Parcels with Armor

D2

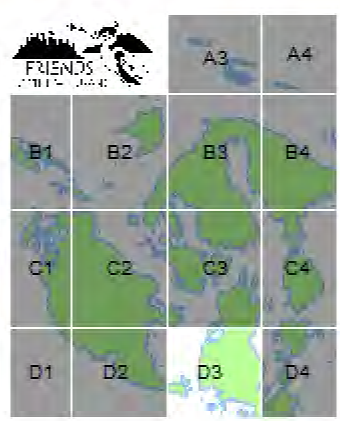


Armor Impacts To Forage Fish Habitat



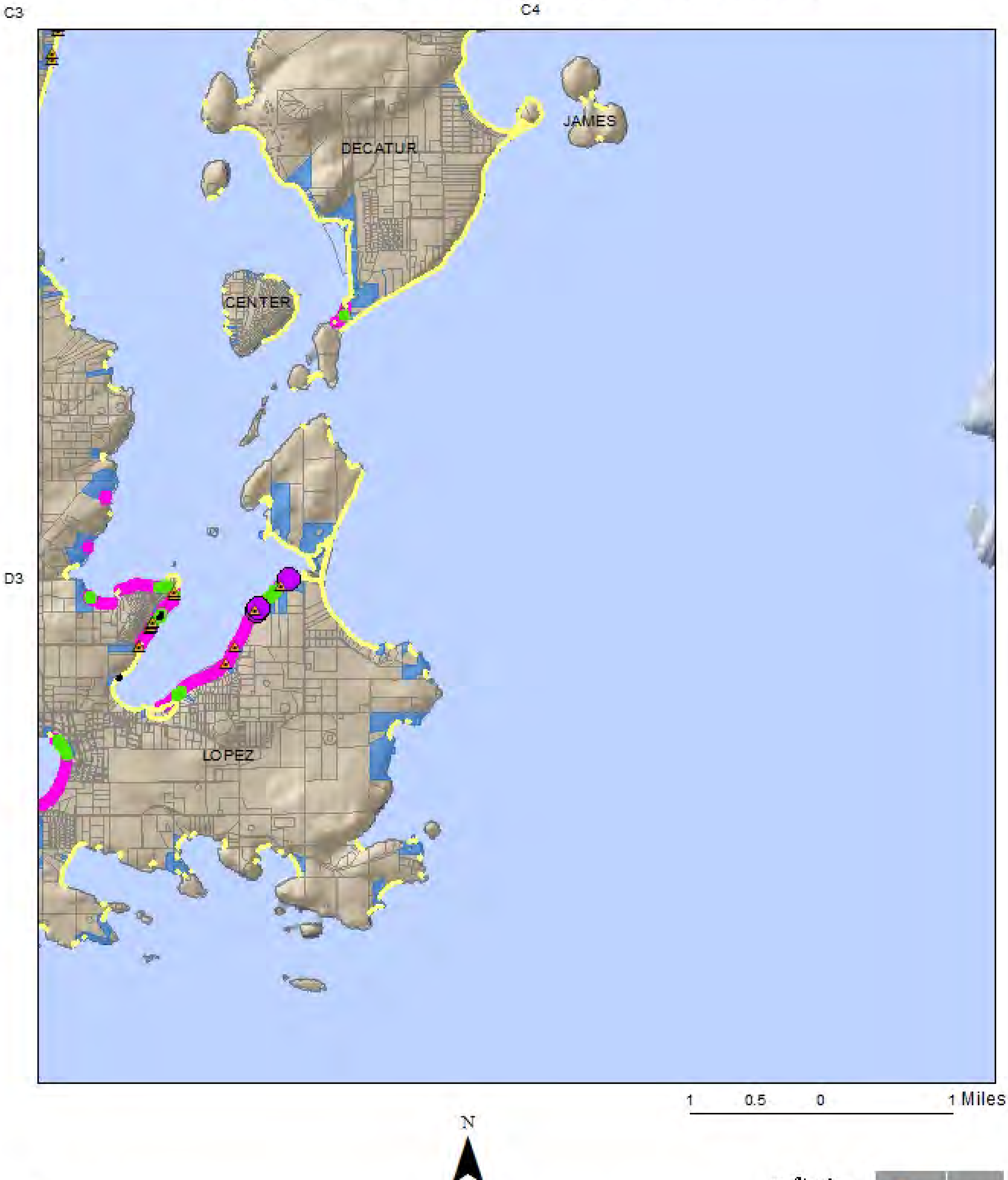
Legend

- Impact to Sediment Supply in Drift Cell With Documented Spawn
- Impact to Sediment Transport in Drift Cell With Documented Spawn
- Direct Burial of Documented Spawn Habitat
- Groin Impact to Sediment Transport in Drift Cell With Documented Spawn
- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- All Parcels with Armor



D3

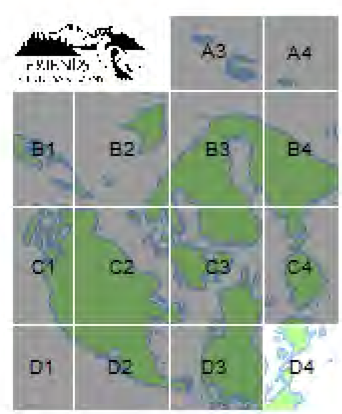
Armor Impacts To Forage Fish Habitat



Legend

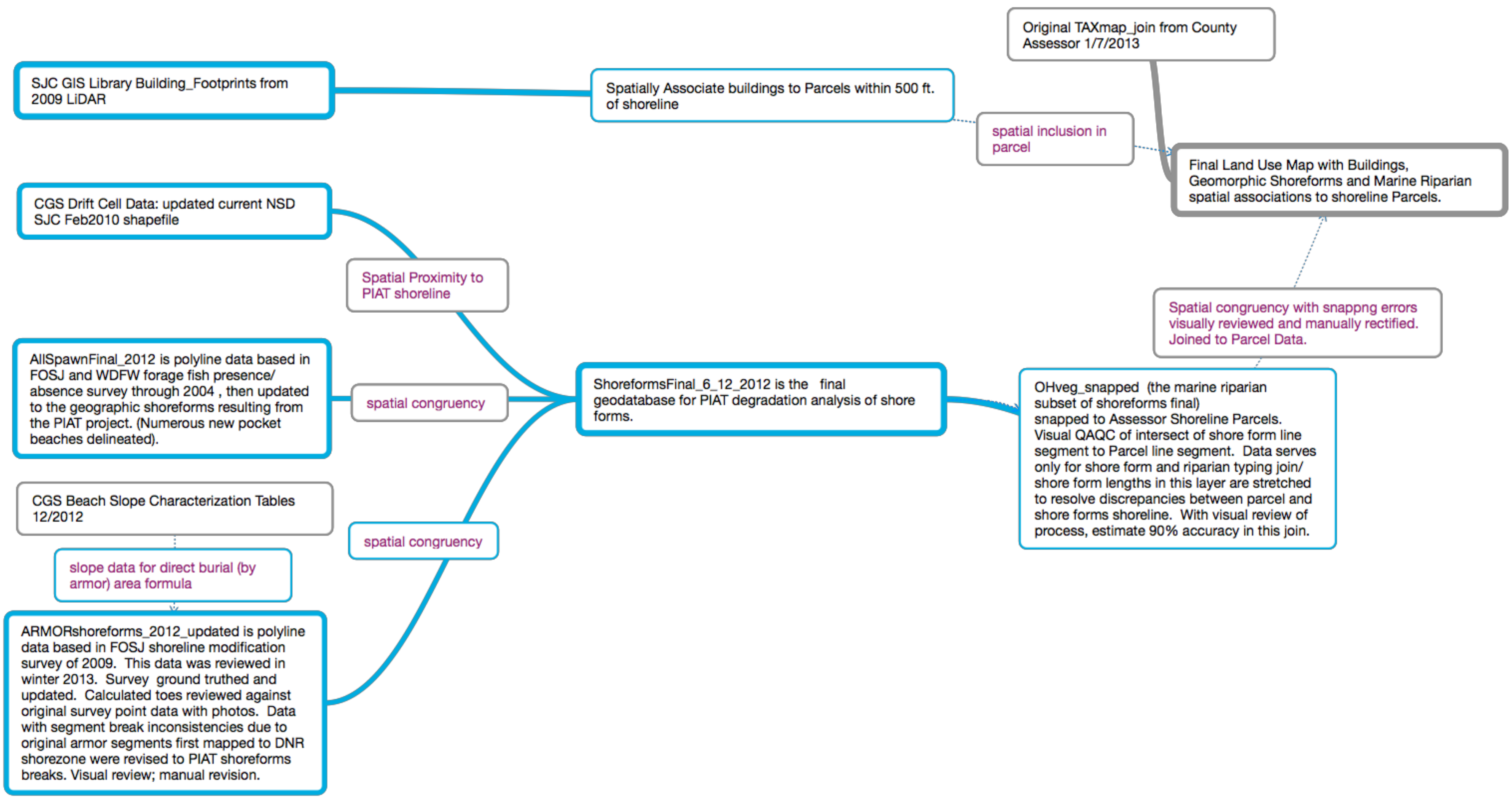
- Impact to Sediment Supply in Drift Cell With Documented Spawn
- Impact to Sediment Transport in Drift Cell With Documented Spawn
- Direct Burial of Documented Spawn Habitat
- Groin Impact to Sediment Transport in Drift Cell With Documented Spawn
- Documented Forage Fish Habitat
- Potential Forage Fish Habitat
- All Parcels with Armor

D4



Appendix A. GIS Data and Methods Summary

Data Development Outline for spatial joining of geological shoreform, marine riparian, shoreline modification, sea level rise, drift cell and building footprint data to Assessor's Parcel Data:



Supporting Data Summary / Shoreline Development Patterns in San Juan County:

1) Developed and Not Yet Developed Shoreline Parcels:

Parent Data: SJ Co. Tax Parcel Data, January 2013 is clipped at 200 ft. from the shoreline; then joined to PIAT Shoreforms (Artificial, Barrier Beach, Embayments, Feeder Bluff, Pocket Beach, Rocky Shoreline, and Transport Zone). W:\files\FOSJ\SLRCI\LandUse_2_24.gdb\LandUse_2_24_2013. The "AllParcel_ID" field is added and populated to give each landuse record its own identifier.

Any records with a zero waterfront length were removed to create "Landuse_2_24_2013_WTRfront" which results in all waterfront parcels and their associated shoreform.

W:\files\FOSJ\SLRCI\LandUse3_19_2013.gdb\Landuse_2_24_2013_WTRfront TABLE:

Field Name	Data Type
OBJECTID	Object ID
Shape	Geometry
PIN	Text
ALTPin	Text
Island	Text
WF_LGTH	Double
District	Text
Acres	Double
TaxPurpose	Text
Tidelands	Double
TidelandFt	Double
TA_ID	Double

WF_LGTH field used to islolate shoreline parcels.

Field Name	Data Type
Neighborho	Text
Region	Text
Cycle	Long Integer
prop_id	Double
Owner	Text
Address_1	Text
Address_2	Text
Address_3	Text
City	Text
State	Text
Zip	Text
Short_Lega	Text
Legal_Acre	Double

Field Name	Data Type
Taxable_Ac	Double
Tax_Code	Double
Tax_Area	Text
Land_Value	Double
Appraised_	Double
Curruse_Va	Double
Bldg_Value	Double
Owner_Last	Text
Use_Code	Double
Tax_Status	Text
Sale_date	Text
Sale_Price	Text
DESCRIPTIO	Text

Field Name	Data Type
AllParcel_ID	Text
ShorelinePARCEL_ID	Text
OpnSp_ID	Text
SJPTesmt_ID	Text
OpenSpace	Text
SJPT	Text
LB	Text
SJPTpres_ID	Text
LBesmt_ID_1	Text
LBpres_ID	Text
BLDG_PIN	Text
Sq_Ft	Double
BLDG_Shape_Length	Double

AllParcel_ID is introduced and retained throughout project to join various datasets back to the parent data.

Added Additional Co. Data Fields with ID fields for Land Bank, San Juan Preservation Trust and Open Open Space.

ShoreForm_Unit_ID	Text
C_Type_FOSJ	Text
Shape_Length	Double
Shape_Area	Double

PIAT Project Shoreform data spatially joined to Tax Parcel Data.

Developed v.s. Not Yet Developed parcels are based on private use parcels, or all parcels that DO NOT meet the following attribute criteria in the Landuse data:

Conservation: "DESCRIPTIO" = 'OPEN-OPEN SPACE' OR "DESCRIPTIO" = 'OPEN-OPEN SPACE W VACA RENTAL' OR "DESCRIPTIO" = 'OPEN-OPEN SPACE W/CONS ESMNT' OR "DESCRIPTIO" = 'OPEN-OPEN SPACE WITH DOCK' OR "SJPT" = 'esmt' OR "SJPT" = 'Pres' OR "LB" = 'esmt' OR "LB" = 'preserve'

Public and Education: "DESCRIPTIO" = 'EDUCATIONAL SERVICES' OR "DESCRIPTIO" = 'GOVERNMENTAL SERVICES' OR "DESCRIPTIO" = 'PARKS' OR "DESCRIPTIO" = 'SMALL ISLANDS - US GOVT.'

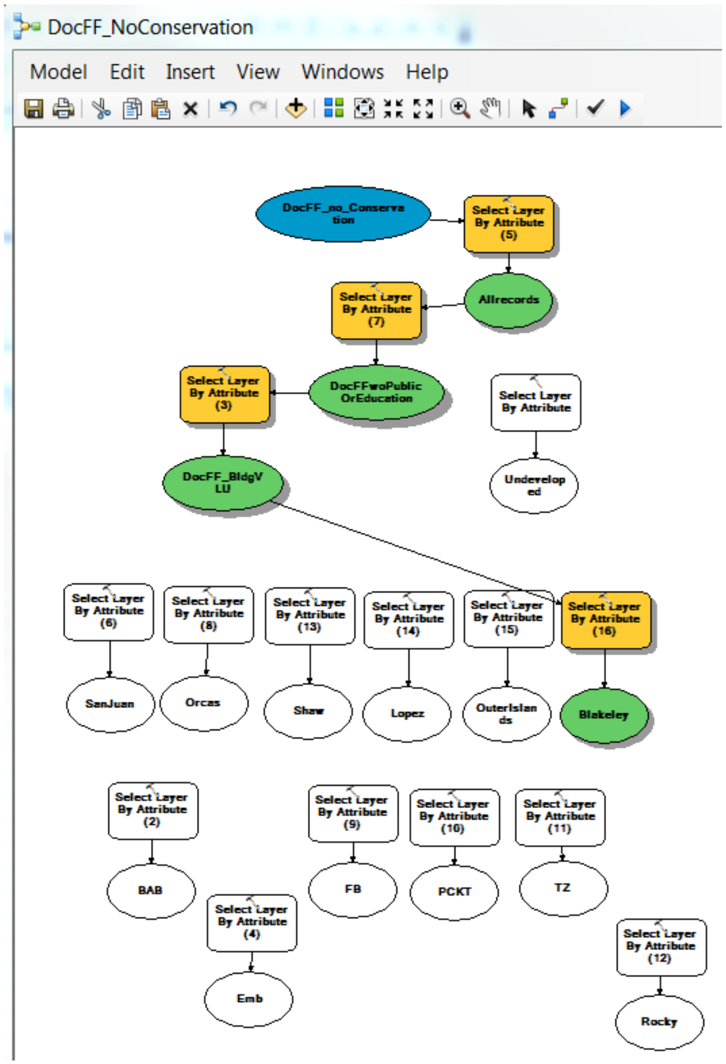
a) With the private parcels defined, A subset of “Not Yet Developed” is isolated using the SJ Co. Assessor’s formula which includes both building codes and building value.

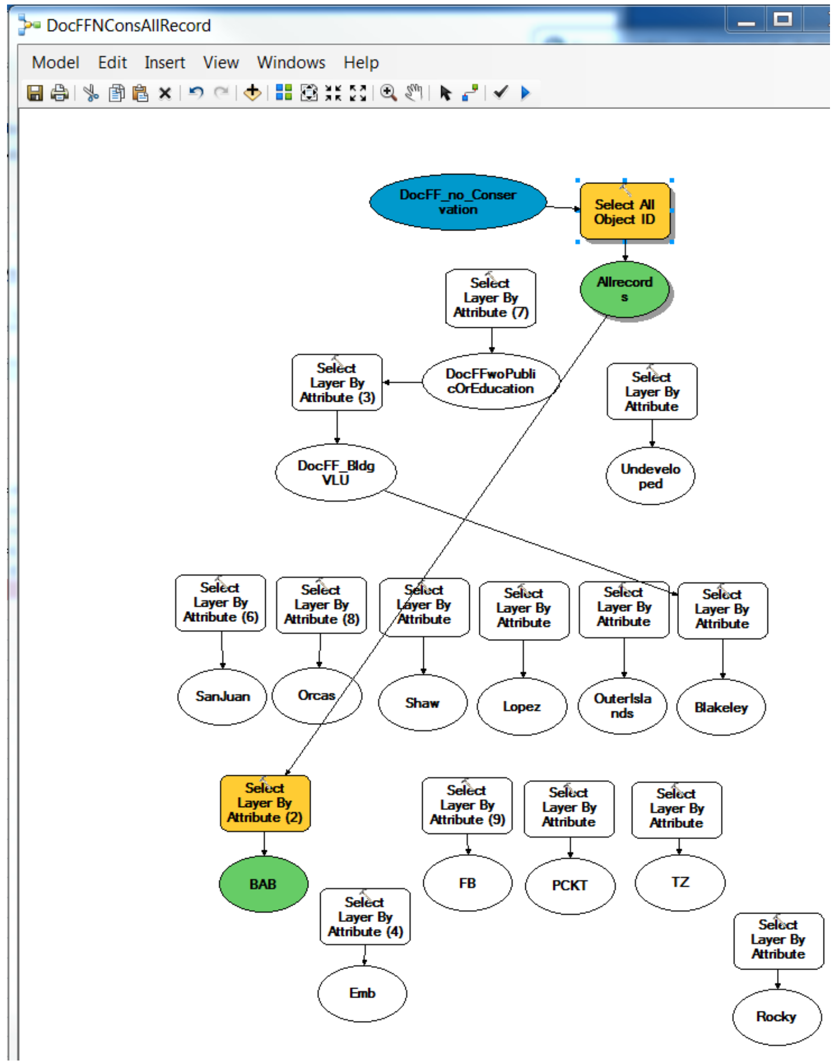
   "Use_Code" = 1800 OR "Use_Code" = 9100 OR "Bldg_Value" <= 9999 (the assumption being that if a lot has $10,000 improvement, it is a septic system and will be developed) (the codes are 1800=UNDEVELOPED RESIDENTIAL < 5AC; 9100=UNDEVELOPED LAND/OVER 5.00 AC)

b) The selection is reversed to isolate the “Developed” parcels.

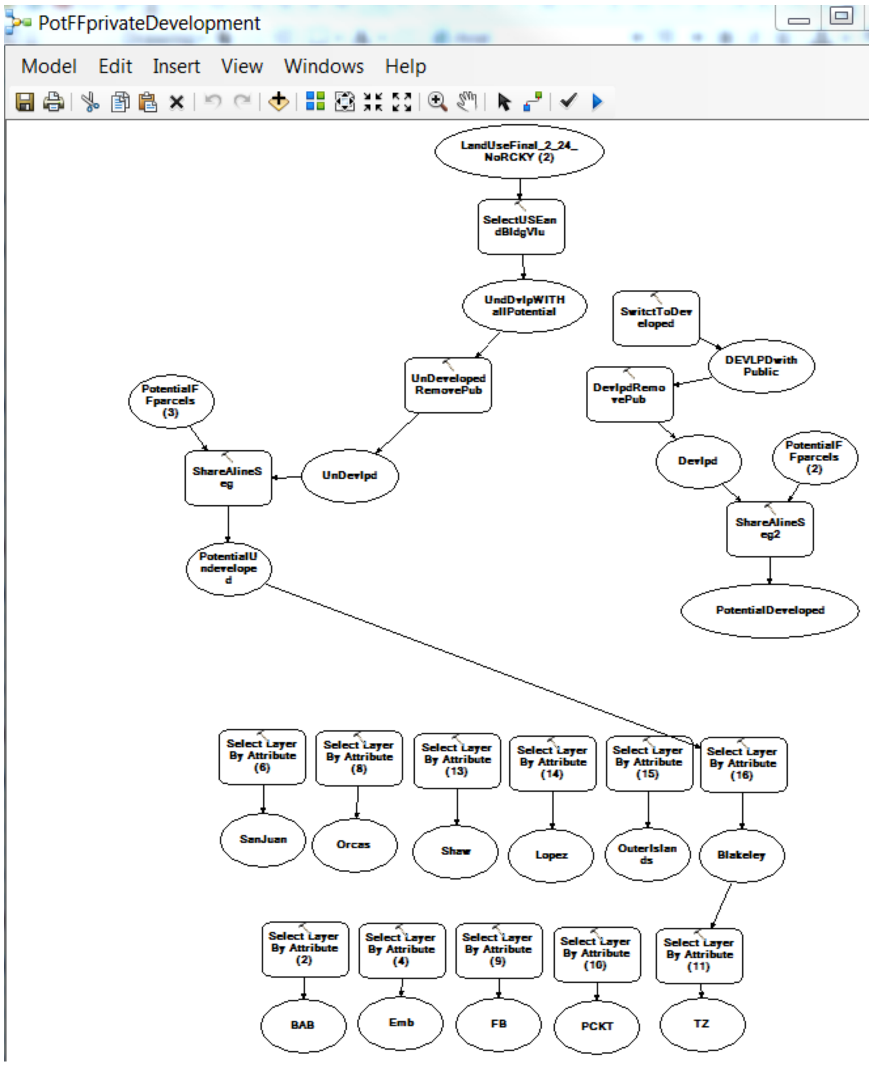
PROCESS MODELS for Developed v.s. Non Developed:

Documented Forage Fish Shoreline by Island and Shoreform:





Potential Forage Fish Shoreline:



2) San Juan County Protected Shoreline Parcels:

Parent Data: “Landuse_2_24_2013_WTRfront” (see field descriptions under “Figure 1”) and “AllSpawnFinal_2012” (FOSJ and WDFW documented forage fish line data) TABLE: (C_Type_FOSJ is = to PIAT_shoreform)

W:\files\FOSJ\Foragefish\foragefish2012.gdb\AllSpawnFinal_2012 TABLE:

Field Name	Data Type
OBJECTID	Object ID
Shape	Geometry
NAME	Text
ISLAND	Text
NAME_2	Text
SOURCETHM	Text
C_Type_FOSJ	Text
DocSPAWN	Text
ShoreForm_Unit_ID	Text
SMELT	Text
SANDLANCE	Text
SAMPLENUM	Text
TIDALELEVA	Text
DATE_	Text
OneEGG	Text
SMPLnum_1	Text
SMPLnum_2	Text
SMPLnum_3	Text
SURVEY_ID	Double
SMELT_IND	Double
SAND_LANCE_IND	Double
RecordsSource	Text
Shape_Length	Double
ID_2012	Double

red rectangles show fields joined to taxmap data.

a) Documented Forage fish: The two tables are joined, then visually editied to create W:\files\FOSJ\SLRCI\Analysis.gdb\DocFF_WITH_Conservation. The segements of the documented forage fish line that lay on San Juan Preservation Trust, Land Bank, or Open Open Space parcels are spatially selected, defined by attribute, then selected by attribute for the Protection Results.

Choose which fields will be visible
- [ ] AllParcel_ID
- [ ] ShorelinePARCEL_ID
- [ ] OBJECTID
- [ ] Shape
- [ ] PIN
- [ ] ALTPin
- [x] Island
- [x] WF_LGTH
- [ ] District
- [ ] Acres
- [ ] TaxPurpose
- [ ] Tidelands
- [ ] TidelandFt
- [ ] TA_ID
- [ ] Neighborho
- [ ] Region
- [ ] Cycle

Choose which fields
- [ ] prop_id
- [ ] Owner
- [ ] Address_1
- [ ] Address_2
- [ ] Address_3
- [ ] City
- [ ] State
- [ ] Zip
- [ ] Short_Lega
- [ ] Legal_Acre
- [ ] Taxable_Ac
- [ ] Tax_Code
- [ ] Tax_Area
- [ ] Land_Value
- [ ] Appraised_
- [ ] Curruse_Va
- [ ] Bldg_Value

Choose which fields will
- [ ] Owner_Last
- [ ] Use_Code
- [ ] Tax_Status
- [ ] Sale_date
- [ ] Sale_Price
- [x] DESCRIPTIO
- [ ] OpnSp_ID
- [ ] SJPTesmt_ID
- [x] OpenSpace
- [x] SJPT
- [x] LB
- [ ] SJPTpres_ID
- [ ] LBesmt_ID
- [ ] LBpres_ID
- [ ] BLDG_ID
- [ ] BLDG_PIN
- [ ] Sq_Ft

Choose which fields will be visibl
- [ ] ShoreForm_Unit_ID
- [x] PIAT_shoreform
- [ ] ShoreForm_ShapeLength
- [ ] Shape_Length
- [ ] Shape_Area
- [x] DocSpawnLgth
- [x] Segment_1
- [ ] SF_ID_2
- [x] SF_Type_2
- [ ] SF_Lngth_2
- [x] SpawnLngth_2
- [ ] Segment_2
- [ ] SF_ID_3
- [x] SF_Type_3
- [ ] SF_Lngth_3
- [x] SpawnLngth_3
- [ ] Segment_3

- [x] Protected
- [x] Not_Protected
- [x] No_Protect_2
- [x] Protect_2
- [x] protection

See Table Sample below:

Table

DocFF_WITH_Conservation

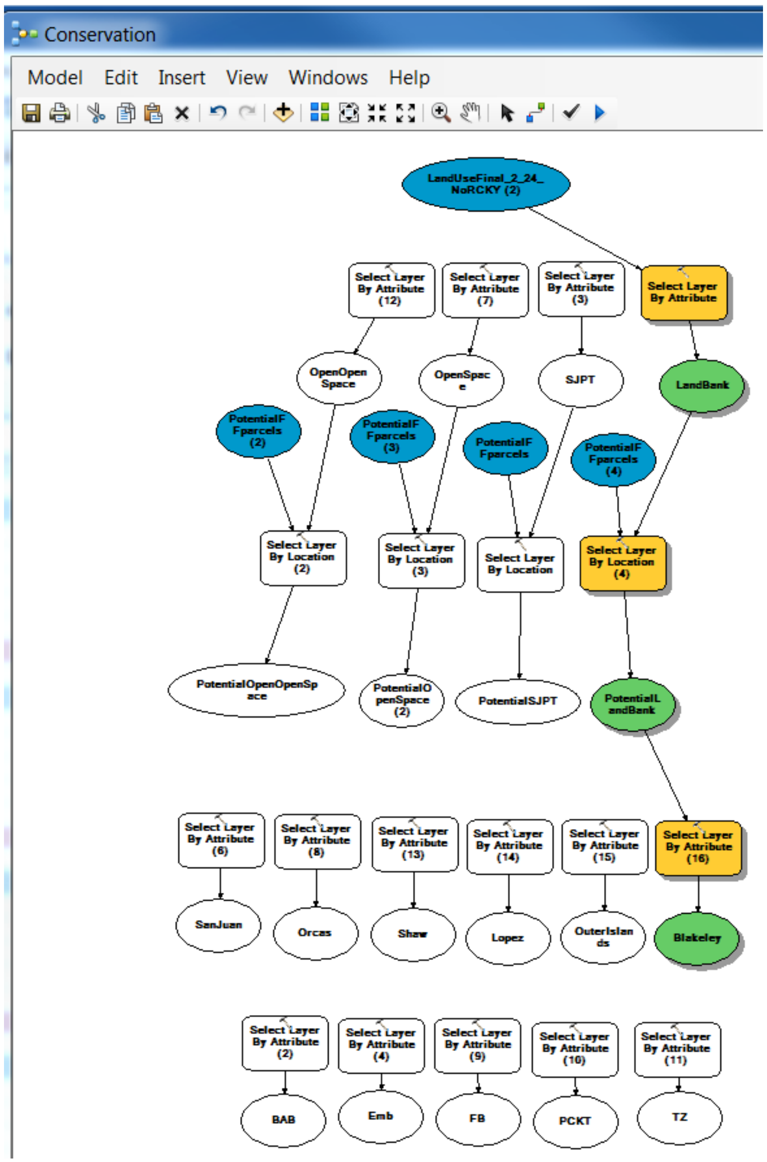
Island	WF_LGTH	DE	SJ	OpenSpa	SJPT	LB	PIAT_shoreform	Sha	DocSpawnLgth	Segment_1	SF_Type_2	SpawnLngth_2	SF_Type_3	SpawnLngth_3	Protected	Not_Protected
Waldron	8314	UN	<N	<Null>	Pres	<Null>	TZ	904	406.802751	224.693837	<Null>	<Null>	<Null>	<Null>	224.69383	182.108914
Shaw	966	OP	22	openOpn	esmt	<Null>	Pocket Beach	226	155.476944	155.476944	<Null>	<Null>	<Null>	<Null>	155.47694	<Null>
Shaw	1200	OP	21	openOpn	esmt	<Null>	Rocky Shoreline	741	681.180399	264.583	Rocky Shoreline	251.410307	Pocket Beach	158.132659	674.12596	<Null>
Shaw	1199	OP	<N	openOpn	<Null>	<Null>	Rocky Shoreline	505	681.180399	416.597399	<Null>	<Null>	<Null>	<Null>	415.90792	<Null>
Shaw	532	OP	57	openOpn	esmt	<Null>	Pocket Beach	374	482.346338	482.346338	<Null>	<Null>	<Null>	<Null>	482.34633	<Null>
Orcas	887	OT	<N	<Null>	<Null>	preserv	BAB	524	1521.462444	895.239063	<Null>	<Null>	<Null>	<Null>	895.23906	626.223381

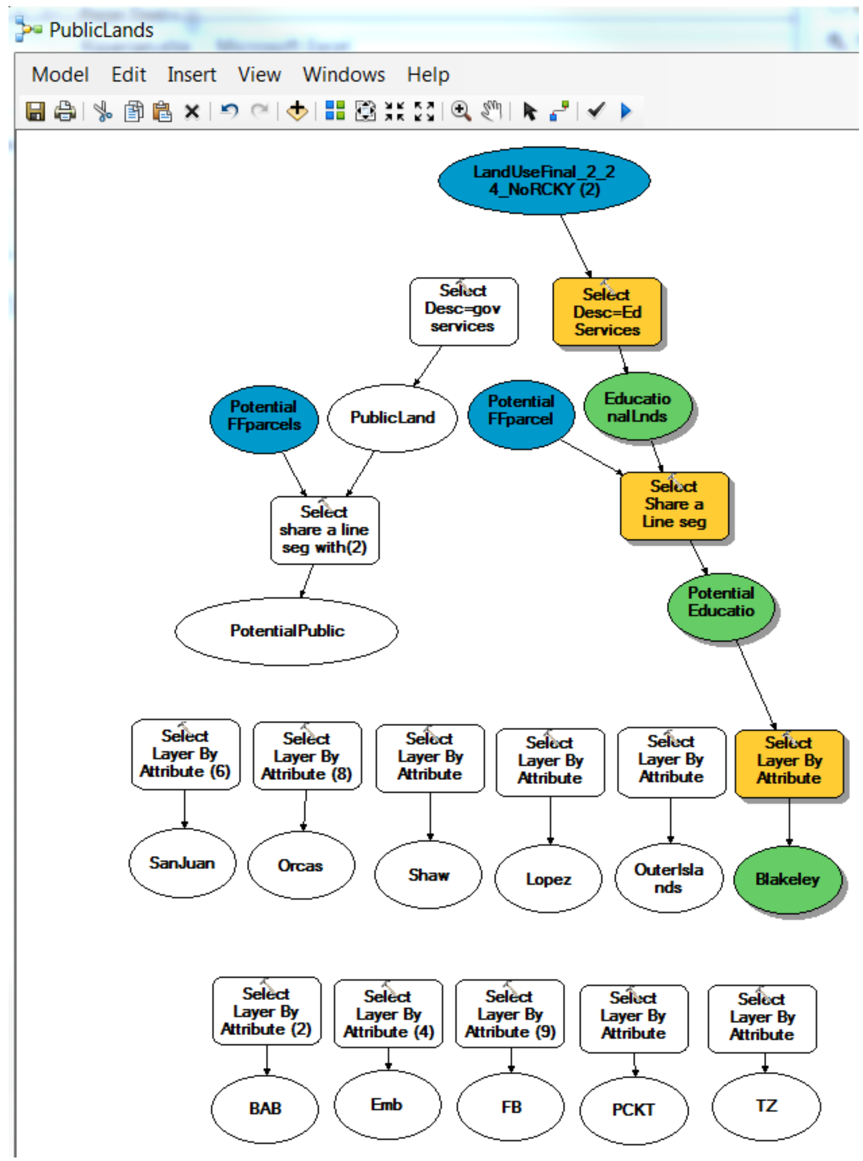
b) Potential Forage Fish: This analysis is done at the parcel level; not the line segment level as defined above for the documented forage fish. The following subsets of the parcel data were developed to isolate the Potential forage fish parcels data layer. The attribute properties for all are identical to the parent data LandUse_2_24_2013.

- Artificial and Rocky Shoreline shore types were selected and excluded by attribute from the parent LandUse_2_24_2013 data, to islolate all soft shore types; resulting in W:\files\FOSJ\SLRCI\LandUse_2_24.gdb\LandUseFinal_2_24_NoRCKY as the potential forage fish parcel data.
- W:\files\FOSJ\SLRCI\Analysis.gdb\DocFFparcels (All LandUse_2_24_2013 Parcels adjacent to AllSpawnFinal_2012 forage fish line data) These parcels were removed from the Potential Forage Fish Parcels dataset.

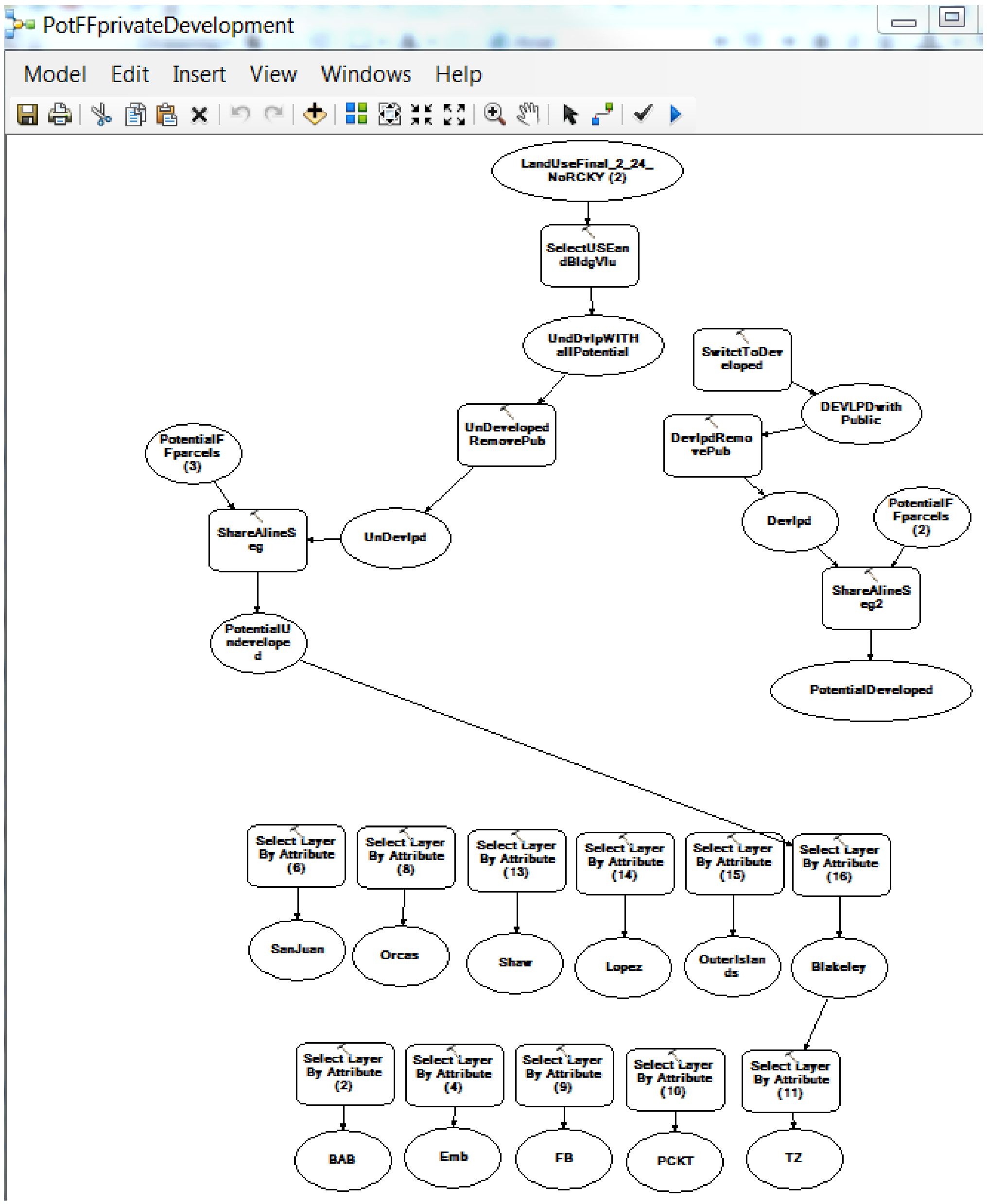
Parcels adjacent to San Juan Preservation Trust, Land Bank, or Open Open Space parcels are spatially selected, defined by attribute, then selected by attribute for the Protection Results.

Potential Forage Fish Conservation, Public or Educational Process Models:





Potential Forage Fish Private Developed and Not Developed Parcel Process Model:



3) San Juan County Armor Parcels And Building Setbacks: Datasets

- Documented Forage Fish Parcels and Potential FF Parcels developed for figure 2.
- AllSpawnFinal_2012 (See table in figure 2 documentation above).
- Potential forage fish line uses PIAT_shoreforms: all softshore that is NOT documented spawn.
- ARMOR line is ARMORshoreforms_2012_updated: Armor data collected in FOSJ Shoreline Inventory 2009. In this project, Documented Forage Fish and Drift Cell Fields have been added. See attribute fields and table sample below:

☑ Shape		☑ Shape_Leng
☑ OBJECTID	☑ Orig_C_Typ	☑ Shape_Length
☑ PIATarmor_	☑ ShoreForm_	☑ DocSPAWN
☑ CalcToeEle	☑ SourceOID	☑ ArmorID
☑ ArmorSegme	☑ ArmorLine_	☑ DriftCELL
☑ UniqueBasi	☑ Verified	☑ C_Type_FOSJ

In table above, ArmorLine_ and SourceOID are fields added from the original survey data prior to snapping to the PIAT shoreforms line and are used in the verification process of the Armor_2012 data. ArmorSegment is the measured line on the PIATshoreforms line and breaks at the end of the shoreform. It is the length used in all calculations. The verification process was completed and the dataset was renamed "Armor_2012_updated" . Sample Table follows:

ArmorShoreforms_2012_updated

O	S	O	Pl	CalcToe	ArmorSegme	UniqueBasi	O	ShoreForm_	SourceOID	ArmorLine_	Verifie	S	Shape_Length	DocSPAWN	ArmorID	DriftCELL	C_Type_FOSJ
5	P	5	6	6	6.536874	SF3003	F	SF3003	607	23.409915	Y	6	6.536874	Yes	57	Y	FB
5	P	5	6	6	18.458485	SF3095	P	SF3095	607	23.409915	Y	1	18.458485	Yes	58	Y	PFB
6	P	6	6	4	281.412252	SF0162	B	SF0162	606	277.521647	Y	2	281.412252	Yes	60	Y	BAB
6	P	6	6	6	90.293447	SF0386	H	SF0386	617	83.923354	Y	9	90.293447	Yes	61	Y	HFB
6	P	6	6	4	40.338666	SF0387	H	SF0387	617	67.704448	Y	4	40.338666	Yes	63	N	HFB
6	P	6	6	4	31.789223	SF0244	F	SF0244	617	67.704448	Y	3	31.789223	Yes	64	N	FB
6	P	6	6	7	100.819465	SF0558	P	SF0558	600	119.030237	Y	1	100.819465	Yes	65	N	Pocket Beach
6	P	6	7	2	27.076118	SF0389	H	SF0389	605	25.954305	Y	2	27.076118	Yes	66	Y	HFB
6	P	6	7	4	108.756426	SF0390	H	SF0390	619	568.142712	Y	1	108.756426	Yes	67	N	HFB

- Building Footprints from SJ Co. GIS department; hand digitized in 2010 from LiDAR survey of 2009.

Choose which fields

- [x] OBJECTID_1
- [x] Shape
- [x] OBJECTID
- [x] Id
- [x] ADDRESS
- [x] HOUSE_NUM
- [x] HOUSE_ABC
- [x] HOUSE_LABL
- [x] STREET
- [x] STREET_TYP
- [x] Sq_Ft
- [x] Island
- [x] FERRY
- [x] PIN
- [x] Latitude
- [x] Longitude
- [x] Source
- [x] Shape_Length
- [x] Shape_Area
- [x] BLDG_ID

Table Sample follows:

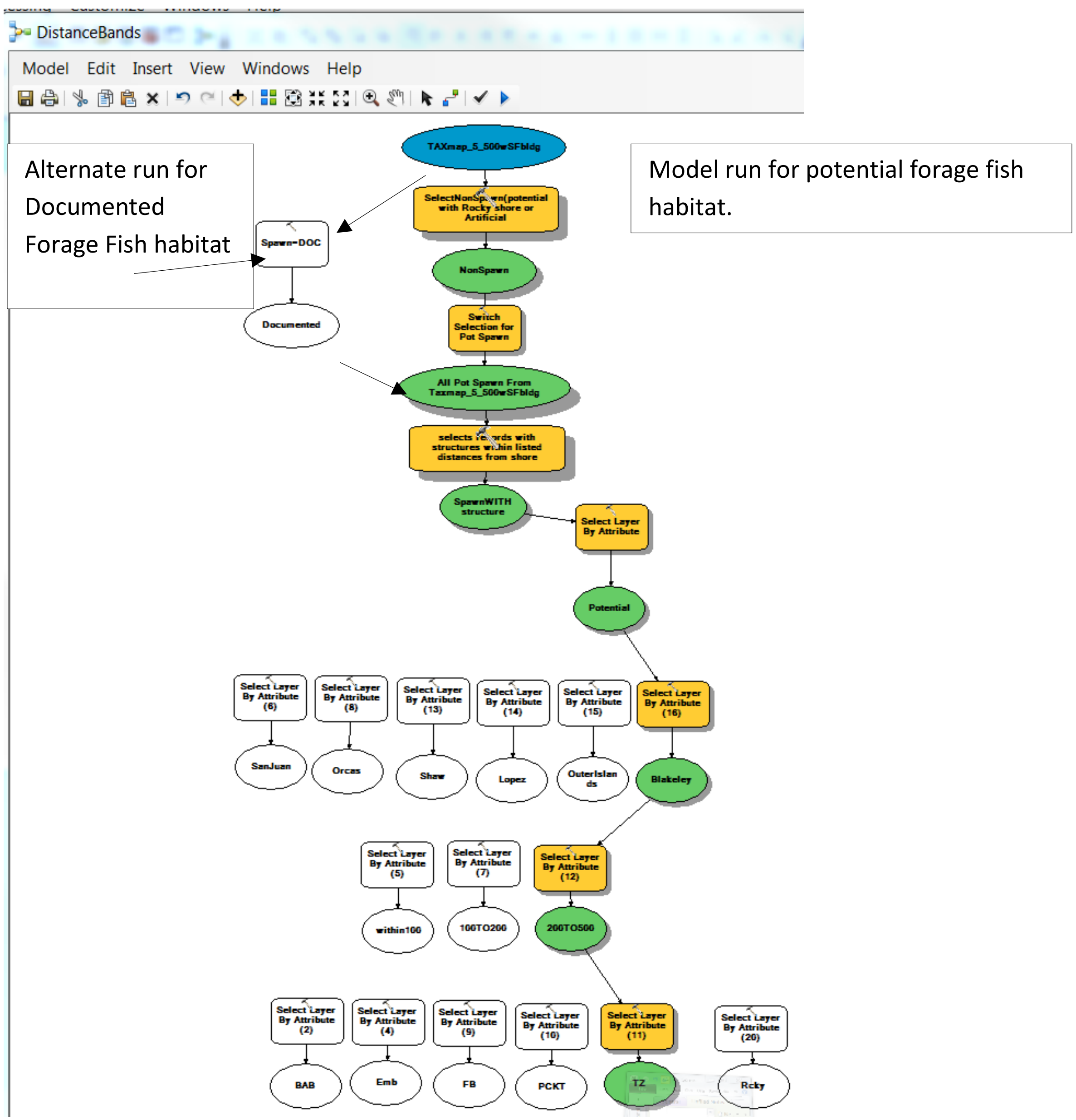
Building_Footprint_Control

OB	Shape *	O	I	ADDRESS	HOUSE_NUM	H	HOUSE_LABL	STREET	STREET_TYP	Sq_Ft	Island	FERRY
1	Polygon	1	0	164 Doe Meadow Ln	164		164	Doe Meadow	Ln	2402.037306	Orcas	Y
2	Polygon	2	0		0			Main	St	262.915228	Orcas	Y
3	Polygon	3	0	238 North Beach Rd	238		238	North Beach	Rd	1376.098299	Orcas	Y
4	Polygon	4	0	531 Fern St	531		531	Fern	St	2951.811641	Orcas	Y
5	Polygon	5	0	236 Prune Aly	236		236	Prune	Aly	6663.234112	Orcas	Y
6	Polygon	6	0	81 Cedar Hill Rd	81		81	Cedar Hill	Rd	2324.434154	Orcas	Y

PIN	Latitude	Longitude	Source	Shape_Length	Shape_Area	BLDG_ID *
271343002000	48° 41' 31.140" N	122° 53' 13.982" W	2009 LiDAR	219.321771	2402.037306	1
271442005000	48° 41' 41.315" N	122° 54' 25.182" W	2009 LiDAR	82.168675	262.915228	2
271455213000	48° 41' 46.639" N	122° 54' 21.660" W	2009 LiDAR	159.105567	1376.0983	3
271454206000	48° 41' 46.224" N	122° 54' 14.432" W	2009 LiDAR	222.117354	2951.811641	4
271455112000	48° 41' 46.736" N	122° 54' 19.169" W	2009 LiDAR	367.154109	6663.234111	5
271542005000	48° 41' 44.603" N	122° 55' 51.404" W	2009 LiDAR	216.018182	2324.434154	6

- Distance from Shore: based on setbacks from the PIAT_shoreforms line data.

Documented Forage Fish and Potential Forage Fish Building Setbacks Process Model:



4) San Juan County Armor Impacts To Forage Fish Spawn Habitat: Datasets

- Documented Forage Fish Parcels and Potential FF Parcels
- AllSpawnFinal_2012
- Potential forage fish line uses PIAT_shoreforms: all softshore that is NOT documented spawn.
- ARMOR line is ARMORshoreforms_2012_updated
- W:\files\CGS\090210download\SJCFB3-shapefiles\SJCFB3-shapefiles\Updated_current_NSD_SJC_Feb2010.shp The Coastal Geological Services Drift Cell Dataset attribute fields:

- [x] OBJECTID
- [x] Shape
- [x] LENGTH
- [x] WS_LLID_NR
- [x] WS_BEGIN_A
- [x] WS_END_AD
- [x] DC_DS_PATH
- [x] DCELL_NR
- [x] CELL_TYP
- [x] Duplicate
- [x] BASIN
- [x] Integer
- [x] Duplicates
- [x] Shape_Length

Table Sample follows:

CoastalGeoDriftCell

OBJE	Shape *	LENG	WS_LLID_NR	WS_BEGIN_A	WS_END_AD	DC_DS_PATH	DCELL_NR	CELL_TYP	Duplicate	BASIN	Integer	Duplicates	Shape_Length
1	Polyline	1510.9	1228814484335	26.801	27.262	LO-10.txt	LO-10	RtoL	-1	San Juan & Whatcom	0	0	1511.441782
2	Polyline	13105.	1229686484685	118.663	122.705	SJ-10.txt	SJ-10	LtoR	-1	San Juan & Whatcom	0	0	13110.238685
3	Polyline	3811.0	1229686484685	123.955	124.608	SJ-9.txt	SJ-9	LtoR	-1	San Juan & Whatcom	0	0	3812.451994
4	Polyline	1276.0	1228814484335	25.449	25.838	LO-11.txt	LO-11	LtoR	-1	San Juan & Whatcom	0	0	1276.537153
5	Polyline	961.20	1228814484335	24.959	25.32	LO-12.txt	LO-12	RtoL	-1	San Juan & Whatcom	0	0	961.548007
6	Polyline	1805.6	1229686484685	2.039	2.677	SJ-8.txt	SJ-8	RtoL	-1	San Juan & Whatcom	0	0	1806.283908
7	Polyline	8596.1	1228814484335	17.553	21.057	LO-13.txt	LO-13	LtoR	-1	San Juan & Whatcom	0	0	8599.249742

Impacts to sediment supply:

The following two files are SUBSETS used specifically to measure overlaps in DriftCell, Spawn, and Armor data; they are NOT suitable for overall counts in armor or spawn because those segments can have two parts; one that overlaps and one that does not.

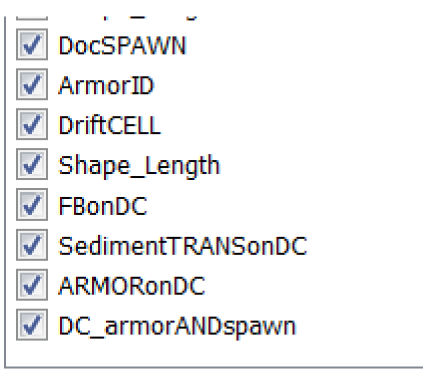
- AllSpawnFinal_2012 (parent file)
  - W:\files\FOSJ\SLRCI\Armor_SLR.gdb\SpawnSegmentsONarmor_3_12_2013
- ArmorShoreformsFinal_2012_updated (parent file)
  - W:\files\FOSJ\SLRCI\Armor_SLR.gdb\ArmorSegmentsOnDC_3_13_2013

The DriftCell Data is in a copy of the original data so that additional fields can be added to complete the relationships with spawn and armor.

- CoastalGeoDriftCell (parent file)
  - W:\files\FOSJ\SLRCI\Armor_SLR.gdb\CGS_driftCell_Analysis_3_13_2013 (COPY)

The spawn and armor subsets have been modified. Overlapping segments of armor and spawn are broken out of the original data.

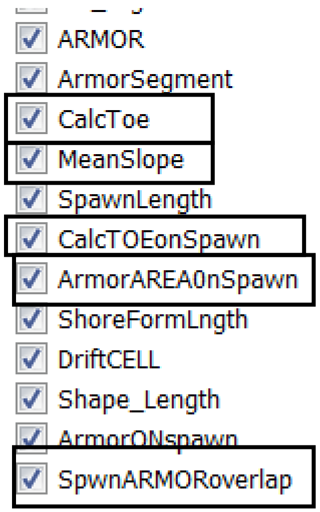
ArmorSegmentsOnDC_3_13_2013 Definition of fields: (Subset of ArmorShoreformsFinal_2012_updated)



- DocSpawn=Y Some portion of the overall armor segment is on documented spawn
- ArmorID: Ties records back to original Armor Shoreforms data
- DriftCELL: “Y”= this portion of the armor segment intersects a drift cell
- FBonDC: The portion of the Armor Segment on a driftcell is on a feeder bluff
- SedimentTRANSonDC: The portion of Armor Segment on a driftcell is on BAB, FB, or TZ

- ARMORonDC: The portion of the Armor Segment that overlaps a Drift Cell
- DC_armorANDspawn: Both armor and documented spawn share a drift Cell. They may or may not overlap each other.

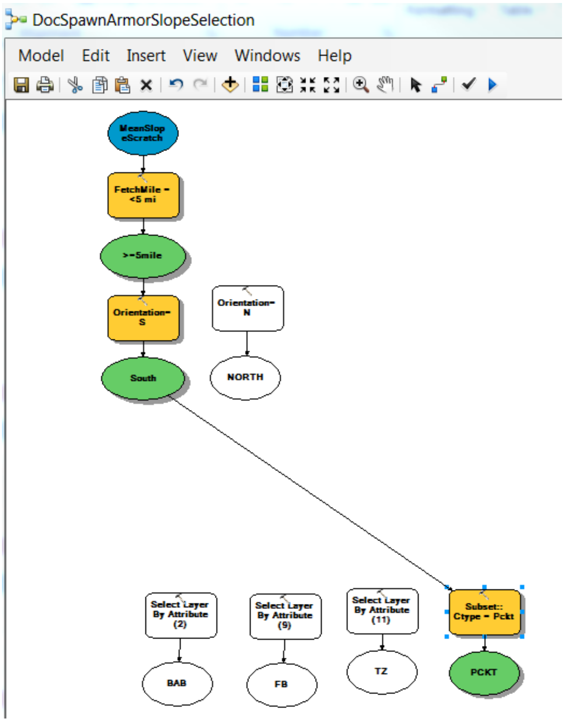
SpawnSegmentsONarmor_3_12_2013 Definition of fields: (Subset of AllSpawnFinal) Spawn Segments in this data are duplicated when a portion of the segment overlaps armor and a portion does not. The segment is broken into two records. Final counts have to be sorted for Y=SpwnARMORoverlap to eliminate the residual spawn segment.



Data in rectangles: Used for Direct Burial calculation. ArmorAREAonSpawn is calculated in the formula: (((10 - [CalcTOEonSpawn]) * 100) / [MeanSlope]) * [SpwnARMORoverlap]

The MeanSlope is calculated from tables based on orientation and fetch of shoreform type and exposure, from Coastal Geological Services.

Direct Burial by Shoreform Process Model:



The CalcToe on spawn converts all calc toes below 4 ft. to 4, as the beach range for spawn habitat is 4 ft. to 10 ft.

- SpawnLength: Overall Length of Spawn Segment
- (Unchecked fields from AllSpawnFinal/not applicable here)
- ShoreFormLngth: Overall length of shoreform the spawn is part of
- DriftCELL: “Y” The spawn is on a drift cell (selection by 100 ft. buffer intersection with driftcell)
- ARMOR: “Y”= There is armor on a portion of the Spawn Segment
- ArmorSegment: The overall length of the armor segment; some portion of which is on the Spawn
- ArmorONspawn: Y/N Y=this portion of the record overlaps armor N=this portion does not overlap armor
- SpwnARMORoverlap: Length of Spawn that is covered by armor

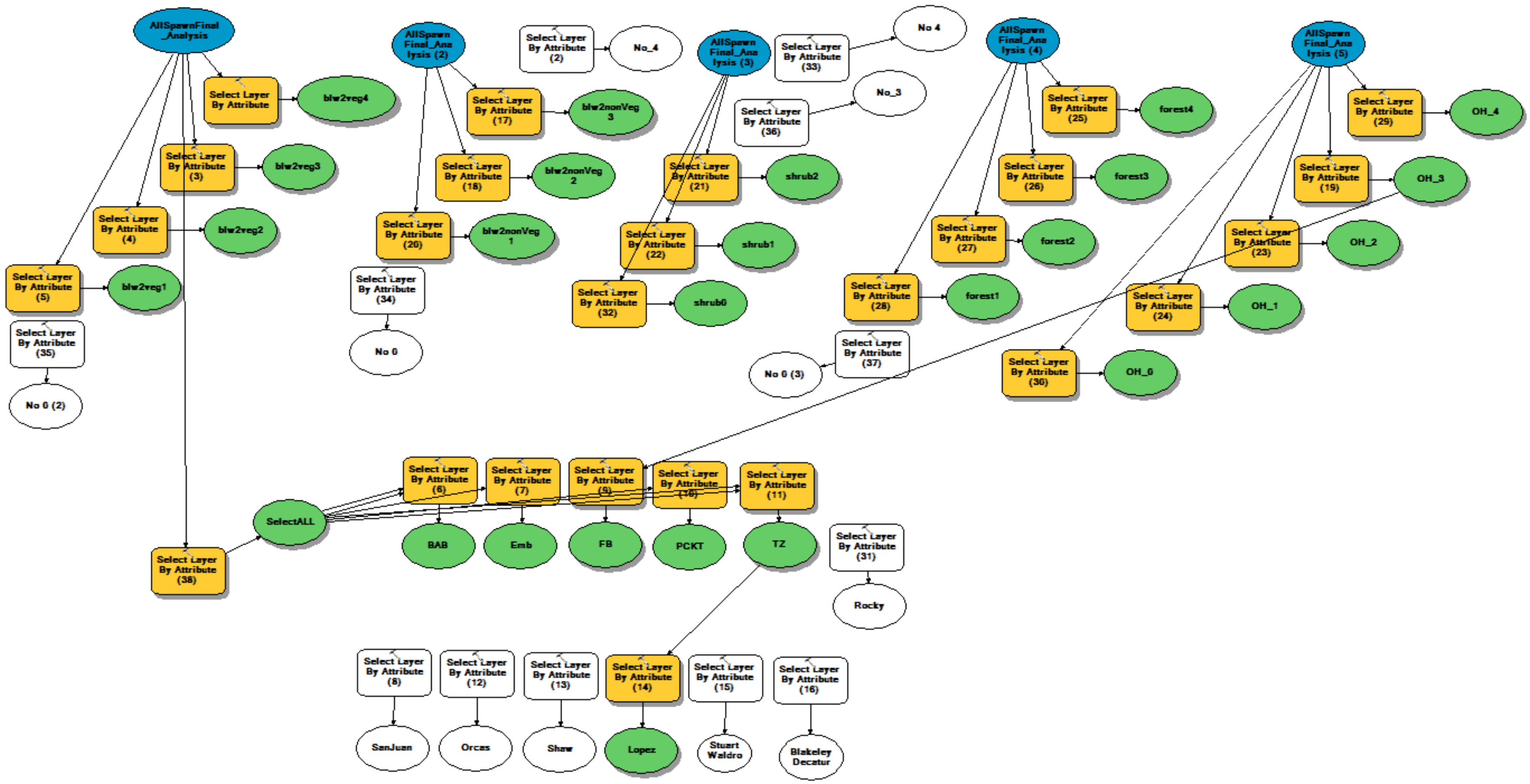
CGS_driftCell_Analysis_3_13_2013

- DC_ID: Unique identifier given to each drift cell record
- ARMOR: Armor buffers_100 ft. that intersect a driftcell = “Y”
- Spawn: Documented Spawn buffers_100 ft. that intersect a driftcell = “Y”
- ArmorFB
- ArmorSEDtrans
- ArmorANDspawn: “Y”=drift cell with armor and spawn; not necessarily congruent

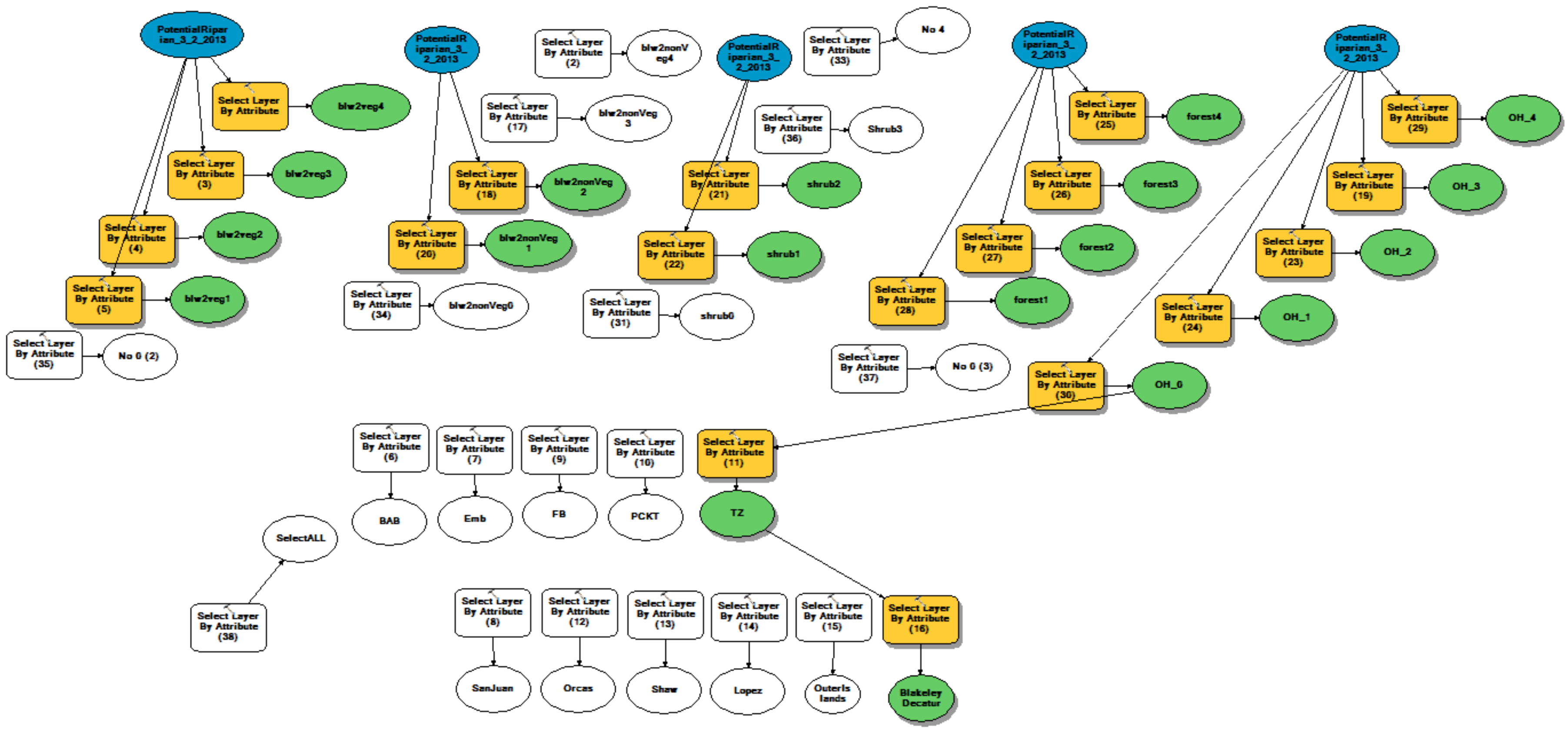
For Drift Cell Counts, records are selected in ArmorSegmentsOnDC_3_13_2013, then Armor_200 Left and right buffers that share a line segment with the selection are selected, then CGS driftcells that intersect the buffer are counted.

5) Forage Fish Habitat and Marine Riparian Conditions
    - AllSpawnFinal_Analysis is a copy of AllSpawnFinal; however, then has numerous fields added to it for project use. AllSpawnFinal_2012 is reviewed Documented Spawn based on documented survey points to date from FOSJ and WDFW. It does NOT include SalmonScape data from WDFW.
      AllSpawnFinal_Analysis has additional fields for Riparian Condition included in this table. It has been joined by shoreform Unit_ID to PIAT Riparian_Final to fill these fields.

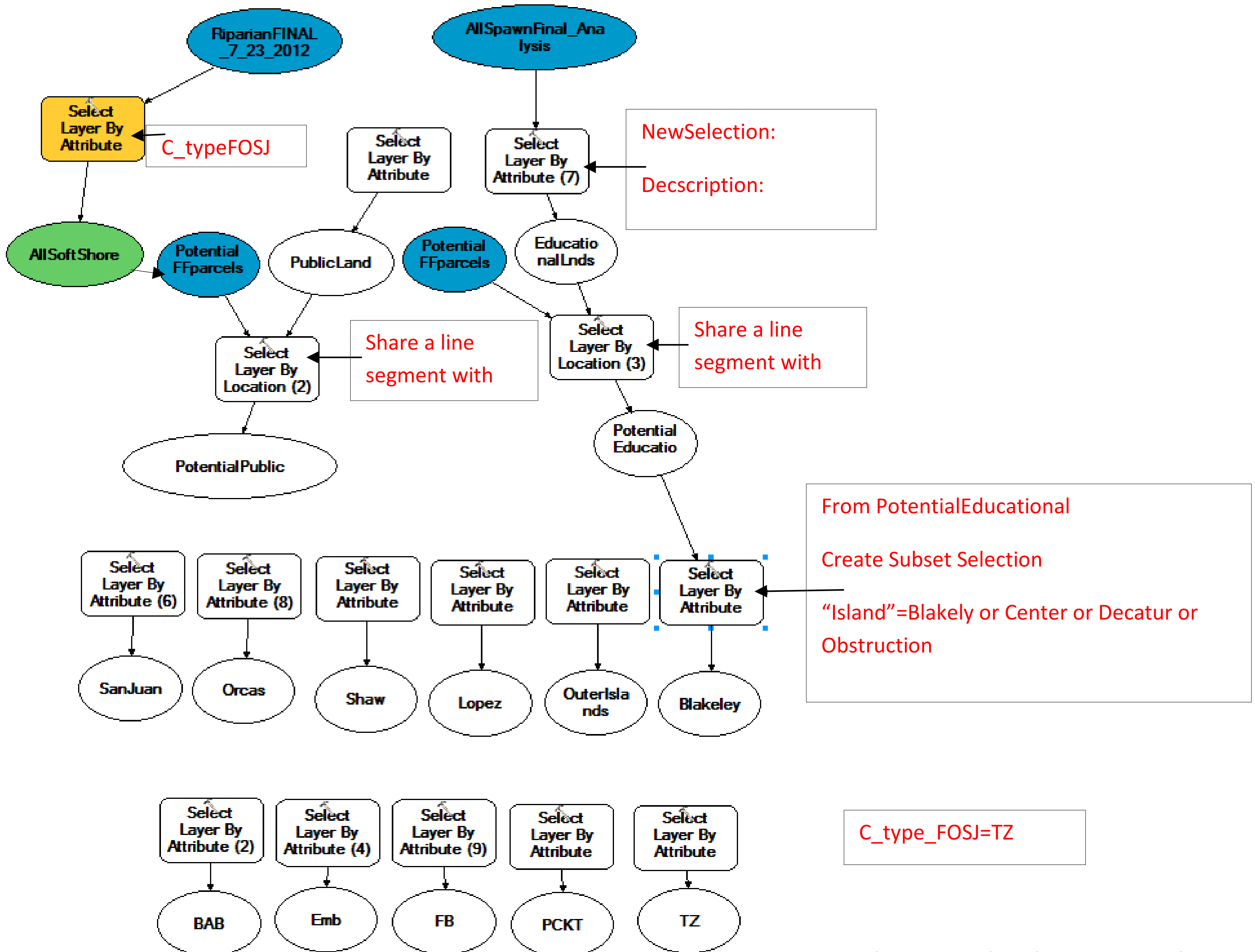
Process Model for Marine Riparian vegetation classes on Documented Forage Fish Spawn Beaches by Geomorphic Shoreform and Island.



Marine Riparian and Potential Spawn:



Marine Riparian Potential and Documented Spawn with Public and Educational Lands Model:



Potential Forage Fish Habitat Riparian layer

Beach Slope Characterization of San Juan County

Sea Level Rise and Cumulative Effects Task 4.3 Report

Prepared for: Tina Whitman, Friends of the San Juans

By: Andrea MacLennan, MS, Coastal Geologic Services (CGS)

COASTAL GEOLOGIC SERVICES

December 11, 2012

Introduction

Forage fish play a key role in marine food webs, with a small number of species providing the trophic connection between zooplankton and larger fishes, squids, seabirds and marine mammals, including ESA listed species such as Chinook salmon and the marbled murrelet. Beach spawning forage fish such as surf smelt (*Hypomesus pretiosus*) and Pacific sand lance (*Ammodytes hexapterus*) are threatened by land use activities along shorelines, where development is also concentrated.

Forage fish spawning areas in San Juan County (SJC) and throughout Puget Sound are especially vulnerable to the impacts of shoreline armoring (Penttilla 2007). Sea level rise is expected to exacerbate the impacts of shoreline armoring on forage fish spawning habitat. In addition, sea level rise and other implications of climate change such as increased storminess are anticipated to result in the increased demand for new shoreline armoring, which would further compound forage fish spawning habitat loss and degrade the nearshore sediment sources (feeder bluffs) that sustain nearshore habitats. The objective of this assessment is to investigate the cumulative effect that shoreline armoring is having on the upper intertidal sand and gravel beach habitats required for spawning substrate by two key forage fish in the Puget Sound region, surf smelt and Pacific sand lance. The geographic scope of the project is San Juan County, Washington.

The objective of Task 4.3 of the larger Sea level Rise and Cumulative Effects project was to complete a beach slope characterization to provide average beach widths across geomorphic shoretypes. The slope data will be used to extrapolate the aerial extent of forage fish spawning habitat and to further understanding of the cumulative effects of armor on forage fish spawning habitat by incorporating these results with those from tidal elevation of spawn studies and other relevant data such as marine riparian mapping.

Methods

Overview

Beach slope was measured in the field from 33 shoreforms including a selection of accessible sites of each major coastal geomorphic shoreform type including: feeder bluffs, transport zones, accretion shoreforms, and pocket beaches (MacLennan et al. 2012, MacLennan et al. 2010). Bedrock shores were not sampled as they are characteristically different and not typically armored. The selection of shoreforms was further stratified by exposure and shore orientation. Shoreforms (of each shoretype) with a maximum measured fetch greater than five miles, and less than five miles were selected. Shoreforms were also stratified by shore orientation (exposure to waves) to either the northern or southern quadrant. Because predominant and prevailing winds and waves are generated from the south, this can result in different conditions such as beach topography, for southern versus northern-facing beaches. Shoreforms that occurred within drift cells that had incurred considerable loss of sediment supply (as reported in MacLennan et al. 2010) were eliminated from the sampling selection, as degraded sediment supply could indirectly affect beach slope. Similarly, pocket beaches with considerable bedrock promontories were not selected for sampling as the bedrock promontories could interfere with beach topography.

Slope Determination

Field measures were conducted by visiting the beach at low tide and placing a measuring tape from the highest elevation of the storm berm to the slope break, located where the high-tide beach transitions to the low-tide terrace (also called sand flat). A sighting level was used to measure height against a stadia rod. Slope measures were then calculated from these data in the office.

Existing CGS in-house topographic survey data from San Juan County Shores were also referenced to supplement field data. Eleven beach slopes were measured from survey data using the same beach features, however, survey based data referenced high resolution beach topographic mapping using Auto CADD. Eight beach slopes were measured from LiDAR data. This unanticipated approach was utilized to increase the number of shoreforms forslope measurements where access and time constraints did not allow field measurements. LiDAR slope measurements were made by creating a profile from a digital elevation model in ESRI ArcMap GIS which was then imported into Auto CADD. Slope measurements were carried out using features consistent with field measurements. Characterization of intertidal and backshore beach substrate was also completed during the beach slope surveys.

Site Distribution

Slopes were measured from a total of 54 shoreforms in San Juan County. The location of each slope measurement location is shown in Figure 1.

Table 1. Structure of shoreform stratification of beach slope measures in San Juan County.

Shoreforms	Exposure	Orientation
15 Feeder Bluffs NOT occurring in drift cells with highly impacted sediment supply	5 with <5 mi fetch	3 S quadrant
		2 N quadrant
	10 with ≥5 mi fetch	5 S quadrant
		5 N quadrant
13 Transport Zones	5 with <5 mi fetch	3 S quadrant
		2 N quadrant
	8 with ≥5 mi fetch	3 S quadrant
		5 N quadrant
13 Accretion Shoreforms	6 with <5 mi fetch	3 S quadrant
		3 N quadrant
	7 with ≥5 mi fetch	4 S quadrant
		3 N quadrant
13 Pocket Beaches	9 with <5 mi fetch	3 S quadrant
		6 N quadrant
	4 with ≥5 mi fetch	3 S quadrant
		1 N quadrant

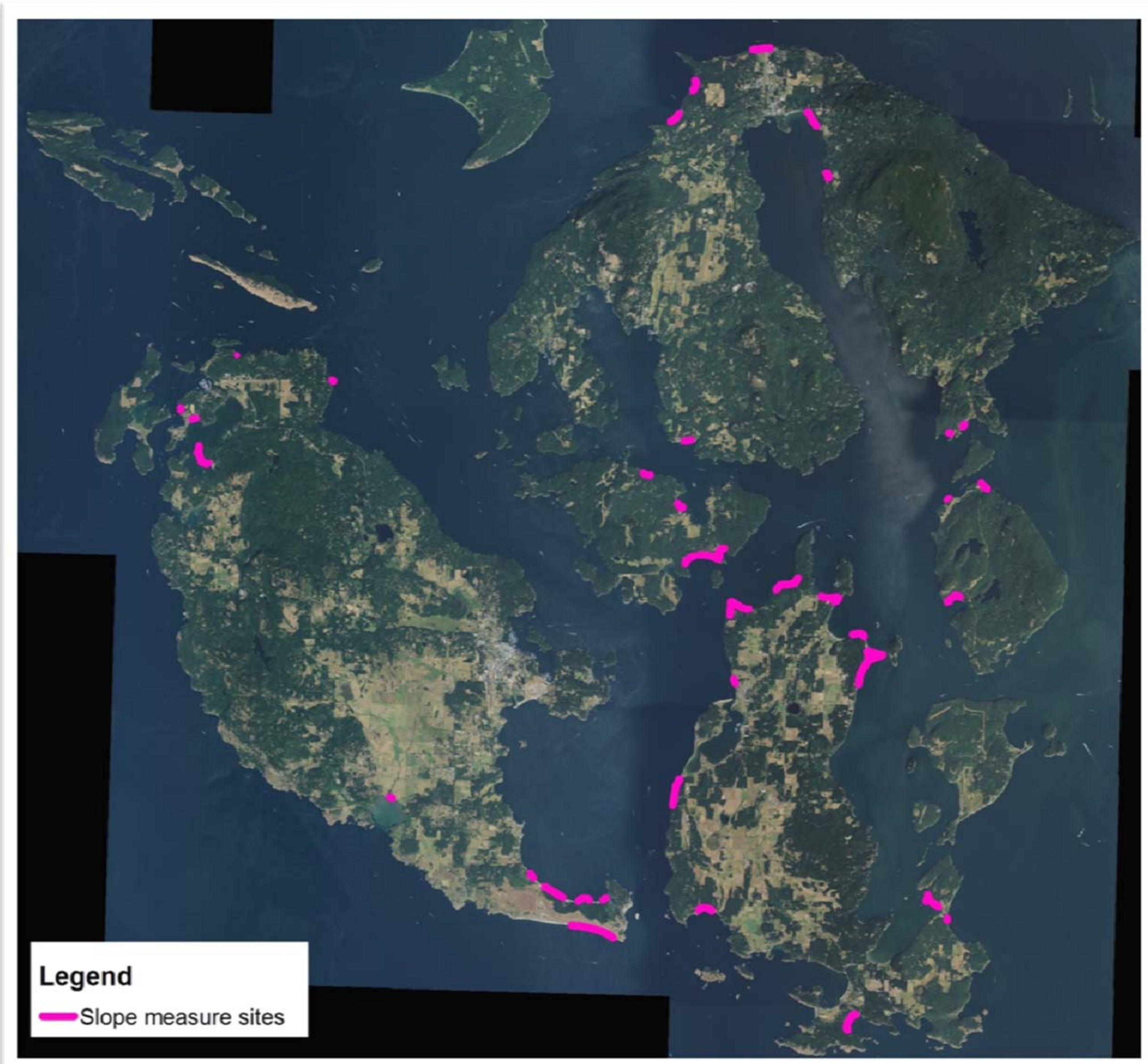


Figure 1. San Juan County beach slope measure sites.

Results

A total of fifty four beach slopes were measured from a stratified random sample of geomorphic shoreforms in San Juan County. Shoreform stratification integrated different levels of fetch and exposure to either the northern or southern quadrant. Slope measures ranged from 4.8:1 to 14.3:1 (horizontal=vertical), with the average slope across all shoreforms measuring 8.7:1. Slope measures were compared across different levels of exposure and orientation regardless of shoretype. North-facing shoreforms, which are not oriented toward the predominant and prevailing wind/wave origin, and are therefore typically exposed to less wave energy, had a steeper mean slope (7.8:1, Table 2), with a narrower range of slopes. South-facing shores were consistently lower slope with an average slope measure of 9.6:1. The range of slopes across all south-facing shores was considerable (4.8:1 – 14.3:1).

Table 2. Comparison of the beachface slope measures across all shoreform types and stratification categories. North/South = shore orientation. <5 or ≥ 5 miles = maximum measured fetch or exposure categories.

ALL Shoreforms	Count	Mean	Min	Max	Stdev
All	54	8.7	4.8	14.3	2.3
N Aspect Only	27	7.8	5.6	12.0	2.3
S Aspect Only	27	9.6	4.8	14.3	2.3
< 5 mile fetch	25	8.7	4.8	14.1	2.3
≥ 5 mile fetch	29	8.7	5.6	14.3	2.3
N < 5 mile fetch	13	8.0	5.8	12.0	2.2
N ≥ 5 mile fetch	14	7.6	5.6	10.2	2.3
S < 5 mile fetch	12	9.5	4.8	14.1	2.2
S ≥ 5 mile fetch	15	9.6	6.4	14.3	2.3

When integrating shoretype, some patterns among the beach slope measures emerged. Across the shoreforms that occur within unmodified portions of drift cells (feeder bluffs, transport zones and accretion shoreforms), feeder bluffs had the lowest mean beach slope across all shore orientations and fetch categories (Table 3). Feeder bluffs typically have relatively high exposure and a narrow upper beach; however, upper beach has not been explored to date. North-facing feeder bluffs with less than five miles of fetch had the highest mean beach slope among all feeder bluffs (7.8:1). The lowest mean slope measured among feeder bluffs were along south-facing feeder bluffs with less than five miles of fetch (11.0:1, Table 4). Feeder bluffs also had the lowest single slope measured across all shoretypes and exposure categories throughout the study area (14.3:1), which occurred along a south-facing beach with over 5 miles of fetch. Pocket beaches consistently exhibited the highest beach slopes, with the mean ranging from 7.0:1 (mean north facing pocket beaches) to 8.5:1 (south-facing pocket beaches). On average the beachface at transport zones were consistently greater in slope than both feeder bluffs and accretion shoreforms (Table 3). Detailed tables displaying the descriptive statistics for each shoretype are found below in Tables 4-7.

Table 3. Comparison of the mean beachface slope across all shoretypes and stratification categories. North/South = shore orientation. <5 or ≥ 5 miles = maximum measured fetch or exposure categories.

Shoretype	All	North	South	< 5 miles	≥ 5 miles
Feeder Bluff	9.6	8.4	10.7	9.7	9.6
Transport Zone	8.3	7.4	9.1	8.8	7.9
Accretion shoreforms	8.9	8.2	9.5	9.5	8.5
Pocket Beach	7.7	7.0	8.5	7.6	8.0

Field explorations of beach slope across San Juan County have not previously been conducted; therefore it is difficult to explain what variables are driving these results. Initial exploration of substrate composition did not reveal any major associations. The seasonality of beach profiles and the mix of slope measure methods are a source of uncertainty in these results. Beach slope measures were conducted in mid-October before the onset of the winter storm season, when beach profiles were likely to resemble the summer beach profile, which are often of lower slope than the winter profile. The late timing of the field venture also resulted in a narrow tide window, which meant that the tidal height of many slope measures was higher than ideal, potentially shortening extent of the beachface that the slope was measured. The mix of methods also may have contributed to the large range of slope measures, particularly across feeder bluffs, which were particularly difficult to find access and adhere to the stratification structure. These potential sources of error may or may not have had a significant effect on these results, but caution should be applied in how these data are used. These data should represent a first-order effort to understand the variability of beach form and structure across San Juan County and within the Salish Sea from which to build and learn more. The intended utility of this data by Friends of the San Juans is well within the range of appropriate data use and the average slope values found in Table 3 are recommended for this application.

Table 4. Feeder bluff beachface slope descriptive statistics across stratification categories. North/South = shore orientation. <5 or ≥ 5 miles = maximum measured fetch or exposure categories.

Feeder Bluff	Count	Mean	Min	Max	Stdev
All	15	9.6	6.9	14.3	2.4
N Aspect Only	7	8.4	6.9	10.2	2.2
S Aspect Only	8	10.7	7.7	14.3	2.4
< 5 mile fetch	5	9.7	7.0	14.1	2.2
≥ 5 mile fetch	10	9.6	6.9	14.3	2.2
N < 5 mile fetch	2	7.8	7.0	8.7	2.1
N ≥ 5 mile fetch	5	8.6	6.9	10.2	2.2
S < 5 mile fetch	3	11.0	7.7	14.1	2.3
S ≥ 5 mile fetch	5	10.6	7.8	14.3	2.2

Table 5. Transport zone beachface slope descriptive statistics across stratification categories. North/South = shore orientation. <5 or ≥ 5 miles = maximum measured fetch or exposure categories.

Transport Zone	Count	Mean	Min	Max	Stdev
All	13	8.3	5.6	12.5	1.9
N Aspect Only	7	7.4	5.6	8.7	1.0
S Aspect Only	6	9.1	6.8	12.5	2.2
< 5 mile fetch	5	8.8	7.2	12.5	2.1
≥ 5 mile fetch	7	7.9	5.6	11.0	1.7
N < 5 mile fetch	2	7.7	7.6	7.8	1.4
N ≥ 5 mile fetch	5	7.5	5.6	8.7	1.7
S < 5 mile fetch	3	9.6	7.2	12.5	1.9
S ≥ 5 mile fetch	3	8.7	6.8	11.0	2.1

Table 6. Accretion shoreforms beachface slope descriptive statistics across stratification categories. North/South = shore orientation. <5 or ≥ 5 miles = maximum measured fetch or exposure categories.

Accretion shoreforms	Count	Mean	Min	Max	Stdev
All	13	8.9	4.8	13.3	2.9
N Aspect Only	6	8.2	5.9	12.0	2.3
S Aspect Only	7	9.5	4.8	13.3	3.3
< 5 mile fetch	6	9.5	4.8	12.7	2.8
≥ 5 mile fetch	7	8.5	5.9	13.3	3.1
N < 5 mile fetch	3	10.0	8.3	12.0	2.9
N ≥ 5 mile fetch	3	6.5	5.9	7.3	2.8
S < 5 mile fetch	3	8.9	4.8	12.7	3.0
S ≥ 5 mile fetch	4	10.1	6.7	13.3	3.0

Table 7. Pocket beach beachface slope descriptive statistics across stratification categories. North/South = shore orientation. <5 or ≥ 5 miles = maximum measured fetch or exposure categories.

Pocket Beach	Count	Mean	Min	Max	Stdev
All	13	7.7	5.8	12.0	1.8
N Aspect Only	6	7.0	5.8	8.1	0.9
S Aspect Only	6	8.5	6.2	12.0	2.4
< 5 mile fetch	9	7.6	5.8	10.6	1.5
≥ 5 mile fetch	4	8.0	6.4	12.0	2.7
N < 5 mile fetch	6	7.1	5.8	8.1	1.3
N ≥ 5 mile fetch	1	6.7	-	-	-
S < 5 mile fetch	3	8.6	6.2	10.6	1.5
S ≥ 5 mile fetch	3	8.4	6.4	12.0	2.0

References

MacLennan, A. J., J. W. Johannessen and S. A. Williams. 2010. Current Geomorphic Shoretype (Feeder Bluff) Mapping of San Juan County, WA – Phase 2: Including Orcas, Clark, Obstruction, Blakely, Decatur, Center, Turn, Brown, Shaw, Pearl, Henry, Stuart, Johns and Waldron Island. Prepared for the San Juan County Marine Resource Committee and the Northwest Straits Commission. 53p.

MacLennan, A. J. and S. Williams. 2012. Resilient and At Risk Priority Nearshore Habitats of San Juan County. Prepared for Friends of the San Juans. 16p.

Pentilla, D. 2007. Marine Forage Fishes in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-03. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.