The Cumulative Effects of Shoreline Armoring on Forage Fish Spawning Beach Habitat in San Juan County, Washington.

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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. 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 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 was San Juan County, Washington. Generous funding for this research was provided by 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 also continue to be granted in SJC 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. Just under 3,500 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, 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 the 80 miles of sand and gravel beaches are armored (the remaining 320+ miles of shoreline is rocky). 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 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.

Methods

A spatially explicit analysis was conducted using the following GIS data layers: documented forage fish spawning habitat, shoreline armoring, shoreform, and drift cell. Technical assistance in the development of project methodology was provided by Andrea MacLennan of Coastal Geologic Services, Dan Penttila of Salish Sea Biological and James Slocomb. GIS analysis and mapping was conducted by Sally Hawkins. 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, changes 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, is also underway but was not completed in time for this report.

Burial of spawning habitat was quantified by the linear shoreline length of impact of armor with a toe elevation at and below 9 feet Mean Lower Low Water (M.L.L.W.). A more detailed quantification would include an assessment of beach profile to support a calculation of the area of spawning habitat buried. Site specific field investigation of beach profiles was beyond the scope of this project, but should be considered for future work on this topic. Impacts to sediment supply, essential to 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, in drift cells with documented and potential spawning beaches. Impacts to sediment transport were evaluated by the number and length of shoreline armoring occurrences with a toe elevation below mean sea level (4.5 M.L.L.W. from NOAA Friday Harbor station applied countywide).

Results

Just over eleven 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 80 miles of potential spawning habitat is documented in San Juan County.

The majority of documented forage fish spawning in San Juan County occurs on pocket beaches, with 44 of 186 shoretypes with spawn and 3.10 miles. Barrier beaches have the next highest occurrence of documented spawn, by length with 2.33 miles at 20 sites. Feeder bluffs also have substantial documented forage fish spawning habitat, with 39 sites and 1.98 miles. Forage fish spawn has also been documented in transport zones, with 28 sites making up just over 1.6 lineal shoreline miles of spawn habitat. The remaining mile or so of habitat occurs along artificial shorelines (those places where the shore has been modified to the extent that the original shoreform classification is uncertain, or along areas incorrectly classified as rocky shorelines.

The majority of armor impacts on documented spawn sites were located on feeder buffs, followed by pocket beaches, barrier beaches, transport zones and then rocky shores. With 2.23 miles of armoring in place at known surf smelt and Pacific sand lance spawning beaches, 20% of documented spawn sites are currently armored. See Forage Fish and Armor Habitat Impacts Mapbook, beginning on page 14 and Table 1. Forage fish spawning habitat and shoreline armoring by shoreform, below.

Table 1. Forage Fish Spawning Beaches and Armoring by Shoreform

Shoreform	***Documented Forage Fish Spawn Beaches - Count***	***Documented Forage Fish Spawn - Length feet (miles)***	***Armored Documented Forage Fish Spawning Beaches - Count***	***Armored Documented Forage Fish Spawn - Length feet (miles)***
Artificial	1	286 ft. (.05 mi)	0	0
Embayment	0	n/a	n/a	n/a
Feeder Bluff	39	10,477 ft. (1.98 mi)	30	3.073 ft.
Transport Zone	28	8,685 ft. (1.64 mi)	9	723 ft.
Barrier Beach	20	11,797 ft. (2.23 mi)	7	1,613 ft.
Pocket Beach	44	16,0359 ft. (3.10 mi)	22	2,986 ft.
Rocky Shoreline*	54	9,244 ft.* (1.75 mi*)	6	226 ft.
total	***186 sites***	***58,384 feet (11.06 miles)***	***71 sites***	***8,621 feet (1.63 miles)***

**NOTE: While shoreform maps of San Juan County have improved greatly over the past year with the completion of geomorphic feeder bluff mapping and pocket beach mapping (Coastal Geologic Services 2010 and 2011) some rocky shore remains incorrectly classified. Spawn not actually present on rocky shores, but shore segments classified as rocky due to resolution issues or errors including: small, unmapped pocket beaches, complex features such as tombolos or areas with heavy forest cover that may have limited classification efforts.*

Direct Burial of Spawning Habitat

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.

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. For this study, direct burial of spawning habitat was quantified by the lineal shoreline length of armoring with a toe elevation of 9 feet M.L.L.W. or below at documented surf smelt and Pacific sand lance spawning sites. The vast majority of armoring at documented sites are currently causing direct burial impacts to spawning habitat. With 2.07 miles of armor along documented forage fish spawning sites, 98% of these sites (1.60 miles) have a toe elevation at or below 9 feet M.L.L.W. See Forage Fish and Armor Habitat Impacts Mapbook, beginning on page 14 and Table 2. Direct burial of spawning habitat, below.

Table 2. Direct Burial of Spawning Habitat
(armored documented forage fish spawning beaches with armor toe elevation below 9 ft. M.L.L.W.)

Shoreform	**Armored documented forage fish spawning beaches with armor toe elevation at or below 9 ft. M.L.L.W. - count**	**Armored documented forage fish spawning beaches with armor toe elevation at or below 9 ft. M.L.L.W. - length Feet (miles)**
Artificial	n/a	n/a
Embayment	n/a	n/a
Feeder Bluff	30	3,073 ft. (mi)
Transport Zone	9	723 ft. (mi)
Barrier Beach	7	1,613 ft. (mi)
Pocket Beach	20	2,817 ft. (mi)
Rocky Shoreline*	5	202 ft. (mi)
total	**71**	**8,428 ft (miles)**

*See note about rocky shoreforms in Table 1,

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 required fine sediment size range 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. 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.

In San Juan County, there are 167 instances of armored feeder bluffs, or 4.94 miles where sediment supply has been impacted. Roughly one third of these armored feeder bluffs (1.3 miles) are located within drift cells with documented spawn. In San Juan County, there are 18 drift cells with armored feeder bluffs that also contain documented forage fish spawn habitat. 58 drift cells have armoring of feeder bluffs, disrupting sediment supply to potential forage fish spawning habitat, or areas where spawn has not yet been documented. These areas are top restoration priorities to ensure adequate sediment supply to maintain forage fish spawning substrate at known spawning sites into the future. Protection of intact feeder bluffs within drift cells with documented forage fish spawning habitat should also be a top management strategy. See Forage Fish and Armor Process Impact Map Book, beginning on page 29 and Table 3. Sediment Supply Impacts, below.

Table 3. Sediment Supply Impacts to Forage Fish Spawn Habitat
(armored feeder bluffs and armored feeder bluffs in drift cells with documented forage fish spawn)

Drift cells	***Armored Feeder Bluffs - count***	***Armored Feeder Bluffs - length***	***Armored Feeder Bluffs in Drift Cells with Documented Forage Fish Spawning Beaches - Count***	***Armored Feeder Bluffs in Drift Cells with Documented Forage Fish Spawning Beaches - Length***
	167	26,076 feet 4.94 miles	58	6,813 feet 1.3 miles

Impacts to Sediment Transport

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. Nearly four miles of armoring with a toe elevation below mean sea level were documented in San Juan County, potentially impacting the transport of sediment to documented and potential forage fish spawning beaches. See Forage Fish and Armor Process Impact Map Book, beginning on page 29 and Table 4. Impacts to Sediment Transport, below.

Table 4. Impacts to Sediment Transport
(armor with a toe elevation below mean sea level defined as 4.5 M.L.W.)

Shoreform	***Armor located below mean sea level - count***	***Armor located below mean sea level – length Feet (miles)***
Artificial	4	2,937 ft. (.55 mi)
Embayment-Estuary	13	1,041 ft. (.20 mi)
Embayment-Lagoon	1	25 ft. (.004 mi)
Barrier Beach	8	1,120 ft. (.21 mi)
Pocket Beach	65	6,396 ft. (1.21 mi)
Rocky Shoreline	72	4,039 ft. (.76 mi)
Transport Zone	18	2,129 ft. (.40 mi)
Feeder Bluff	28	2,544 ft. (.48 mi)
total	***209 sites***	***20,231 feet (3.83 miles)***

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. 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 conducted. 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 5. Overhanging Marine Riparian Vegetation; results shown as for the dominant coverage classes only.

Table 5. Overhanging Marine Riparian Vegetation – dominant coverage class (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.

Conclusions/Management Implications

With over 700 armored beaches and a limited number of documented forage fish spawning beaches, 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, are needed to reduce the impacts of bulkheads and shoreline infrastructure such as roads on beach spawning habitat and the coastal processes that form and maintain suitable spawning substrate.

Top restoration priorities include: restoration to remove armoring from documented forage fish spawning beaches to uncover and restore buried spawning substrate; removal of shoreline armoring from feeder bluffs in drift cells with documented forage fish spawning habitat to restore sediment supply; and removal of shoreline armoring located below mean sea level updrift of documented spawning sites to restore sediment transport. Additional restoration priorities include the removal of 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.

As restoration success is limited by feasibility and high cost, improved protection will play an essential role in ensuring that forage fish spawning habitat and habitat forming processes are maintained into the future. Improved protections are needed to clearly prohibit the construction of new bulkheads at documented forage fish spawning sites or at feeder bluffs in drift cells with document spawning sites. In addition, policies to promote the removal or relocation of existing armoring, perhaps through enhanced repair/replace regulations, are needed countywide. Demand for armoring is expected to increase and the documentation of additional spawning sites is also likely. As such, policies designed to minimize the need for future armoring at all shoreforms and drift cells and for potential as well as documented spawn sites, such as wider building setbacks and protection of vegetative buffers between structures and the shoreline, will be needed. Protection of beach habitats into the future, for fish, wildlife and people, will not be possible through restoration actions alone. Improved protection policies will be required.

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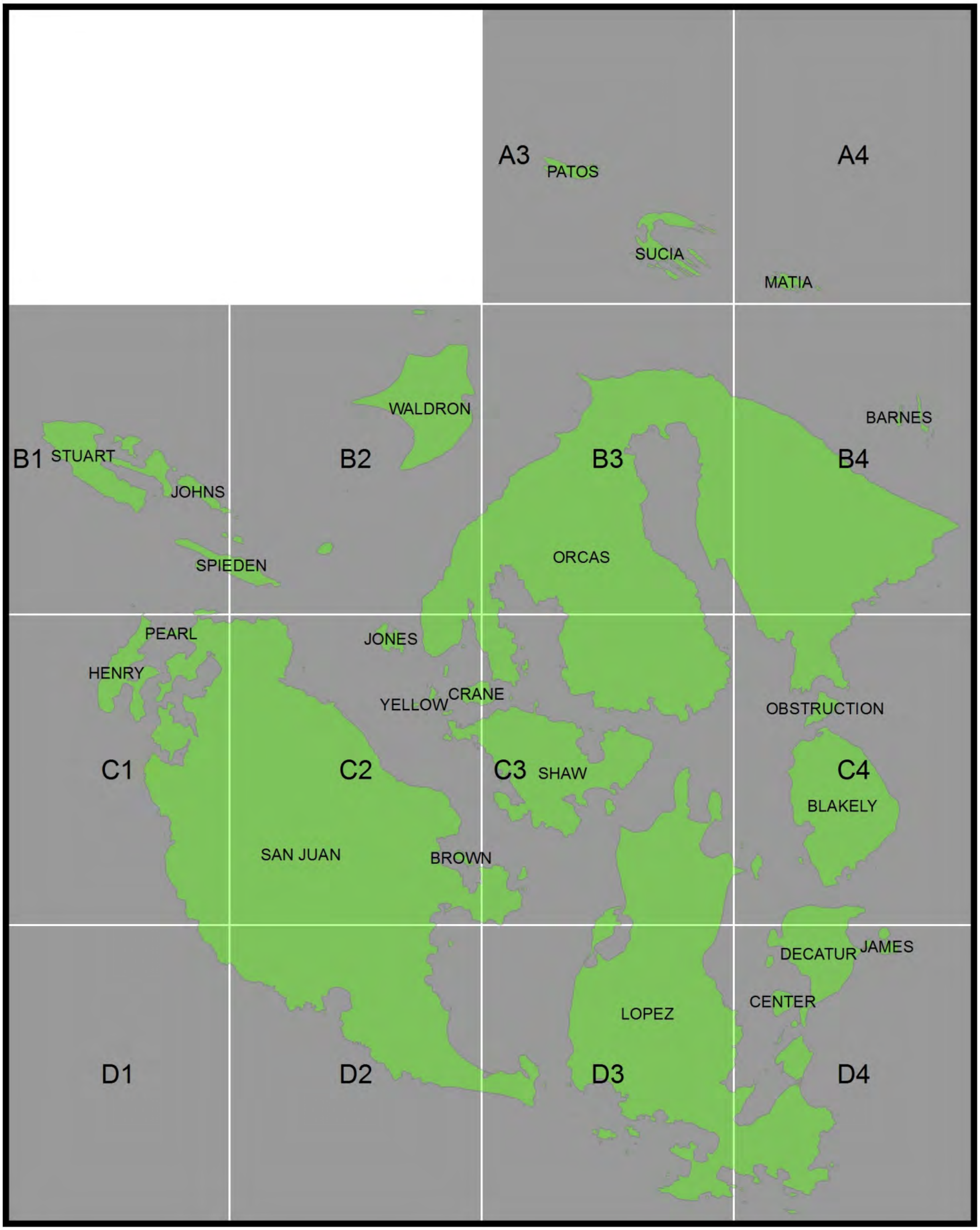
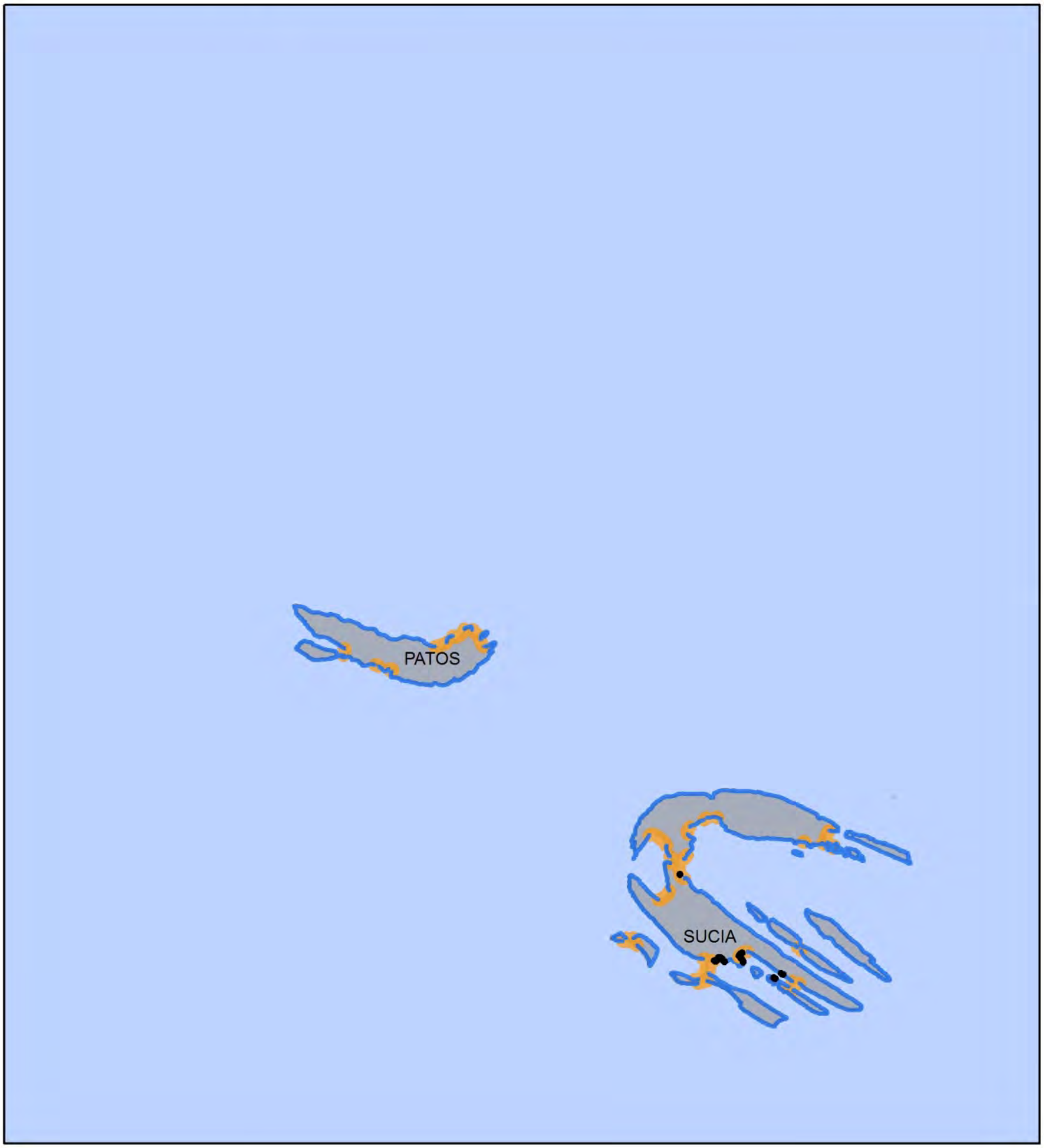


San Juan County
Forage Fish Spawning and Shoreline Armoring Impact Analysis
MAPBOOK

FRIENDS OF THE SAN JUANS

Forage Fish and Armor Habitat Impacts



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LEGEND:

Shoreform

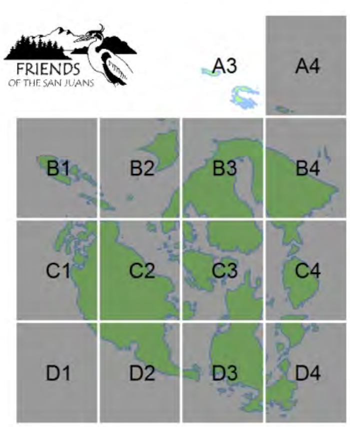
Artificial
Barrier Beach
Embayments - Estuary
Embayments - Lagoon
Feeder Bluff
Pocket Beach
Rocky Shoreline
Transport Zone

Shoreline Armoring

Documented Surf Smelt & Pacific Sand Lance Spawning Habitat

Direct Burial-Documented Spawn Site with Armor Toe 9 ft. and below M.L.L.W.

Roads



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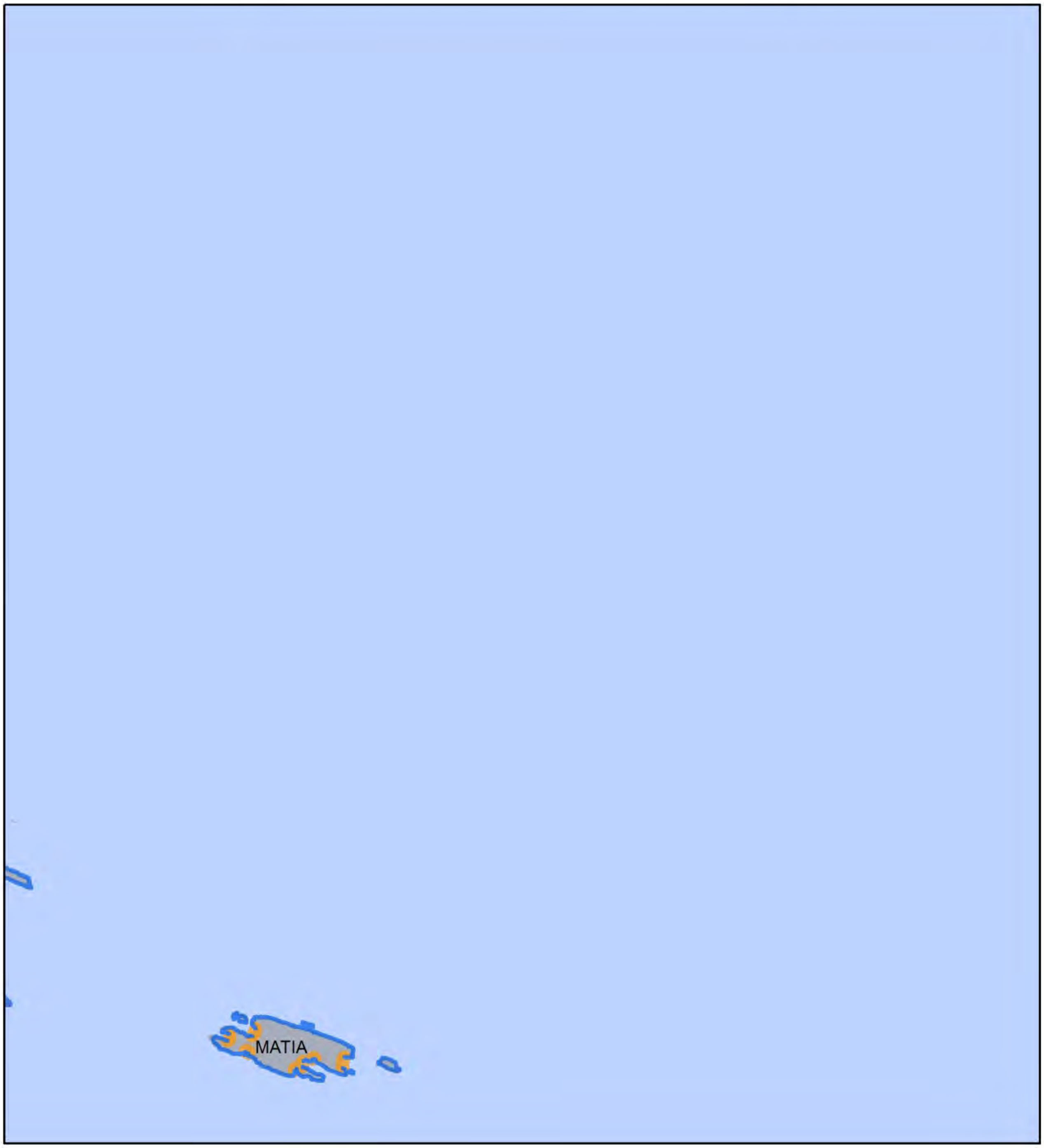
Forage Fish and Armor Habitat Impacts



A3

B3

B4

1 0.5 0 1 Miles

LEGEND:

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Shoreform

Artificial
Barrier Beach
Embayments - Estuary
Embayments - Lagoon
Feeder Bluff
Pocket Beach
Rocky Shoreline
Transport Zone

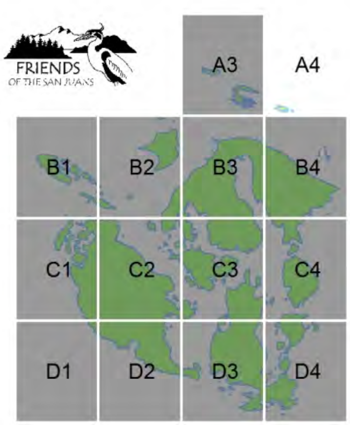
Shoreline Armoring

Documented Surf Smelt & Pacific Sand Lance Spawning Habitat

Direct Burial-Documented Spawn Site with Armor Toe 9 ft. and below M.L.L.W.

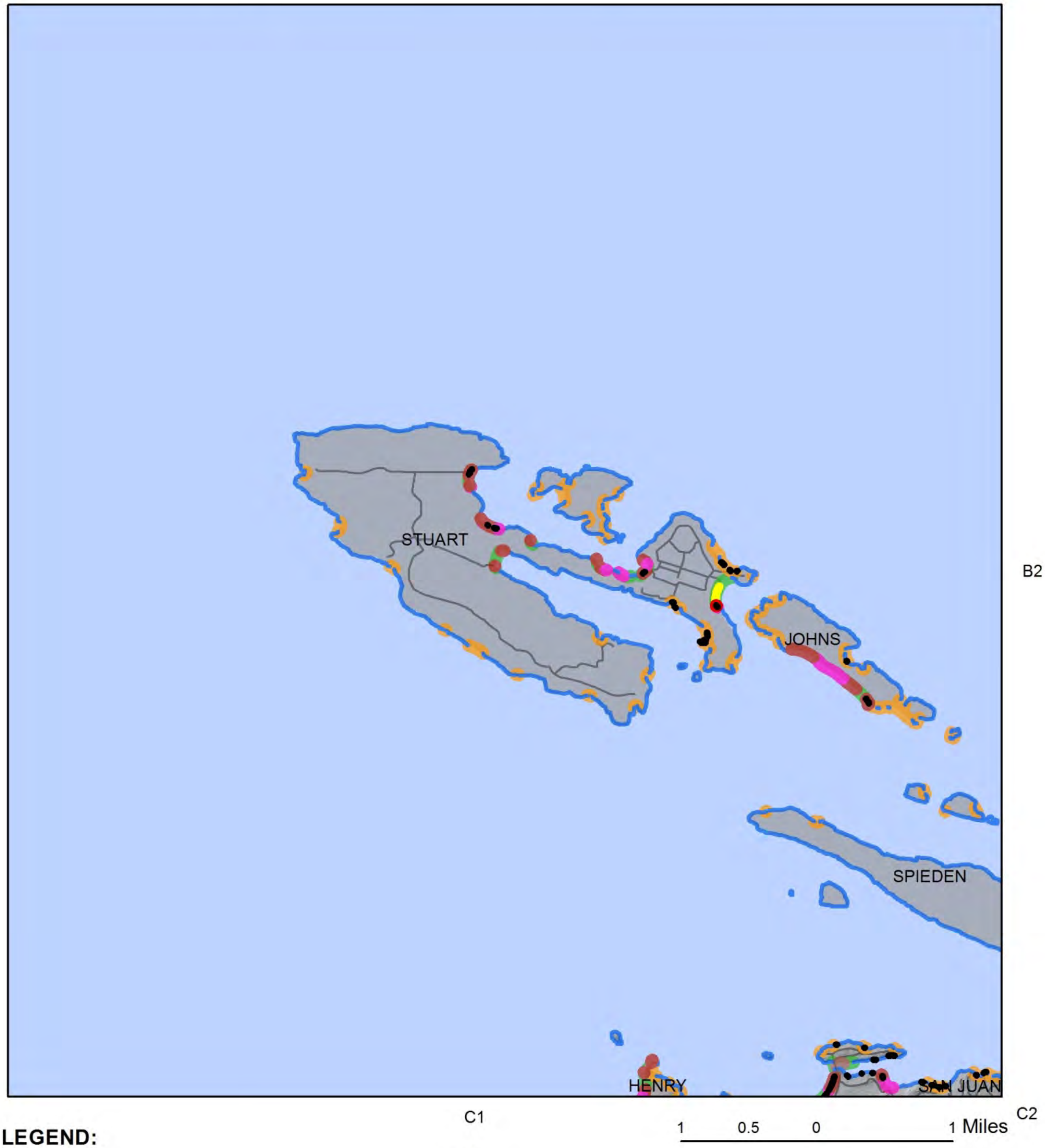
Roads

FRIENDS OF THE SAN JUANS



A4

Forage Fish and Armor Habitat Impacts



LEGEND:

Shoreform

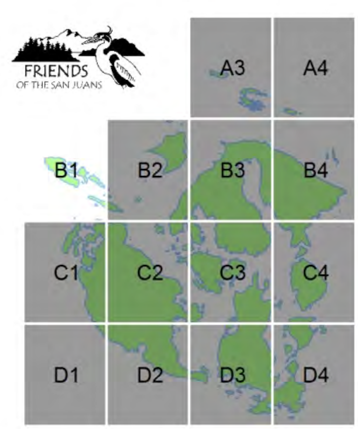
Artificial
Barrier Beach
Embayments - Estuary
Embayments - Lagoon
Feeder Bluff
Pocket Beach
Rocky Shoreline
Transport Zone

Shoreline Armoring

Documented Surf Smelt & Pacific Sand Lance Spawning Habitat

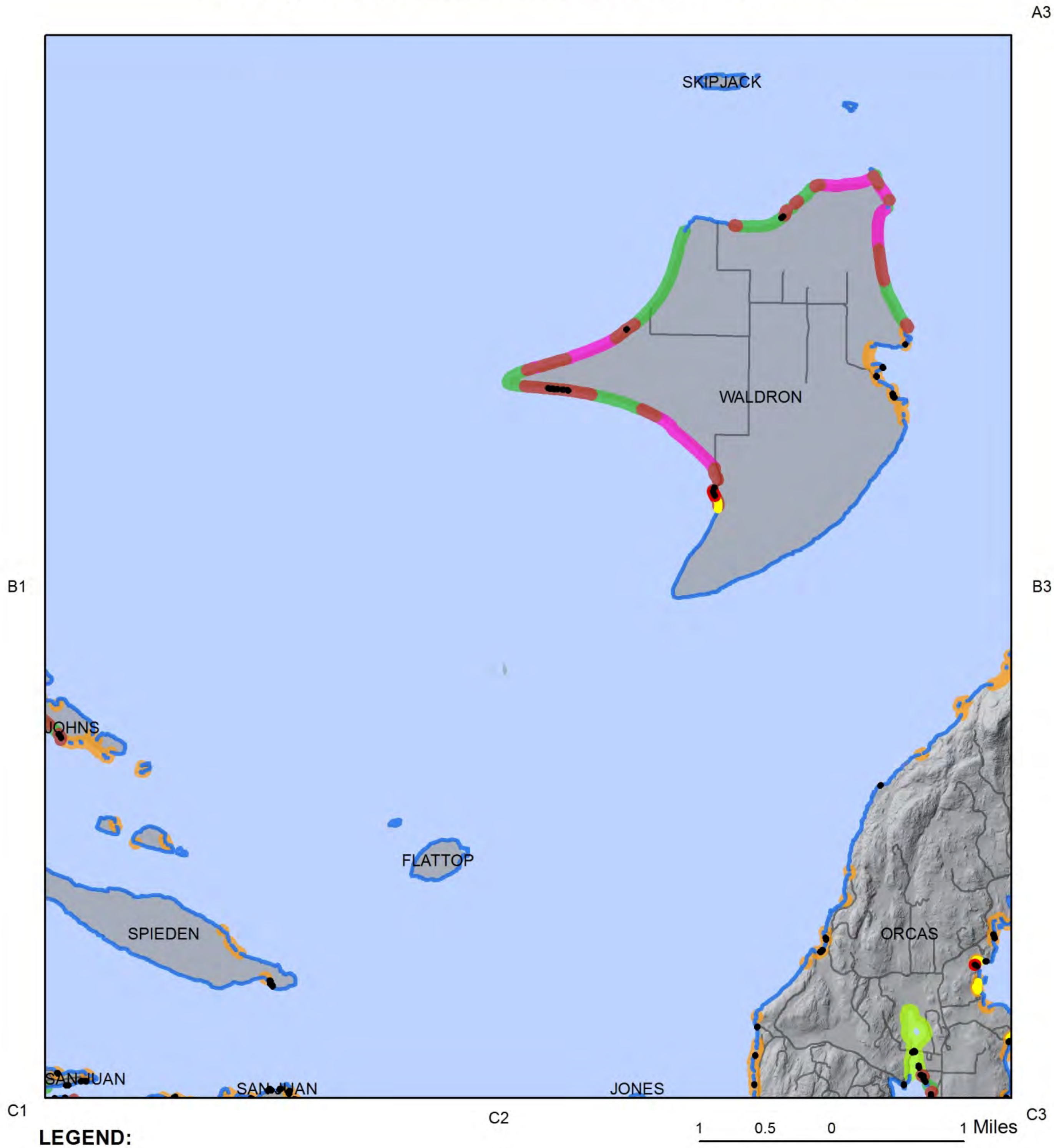
Direct Burial-Documented Spawn Site with Armor Toe 9 ft. and below M.L.L.W.

Roads



B1

Forage Fish and Armor Habitat Impacts

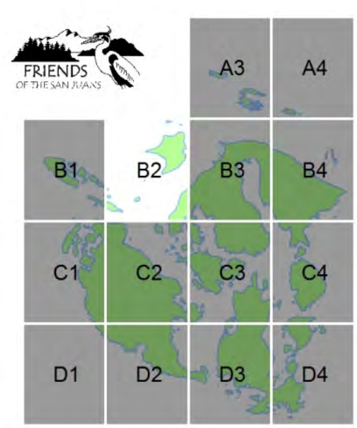


LEGEND:

Shoreform

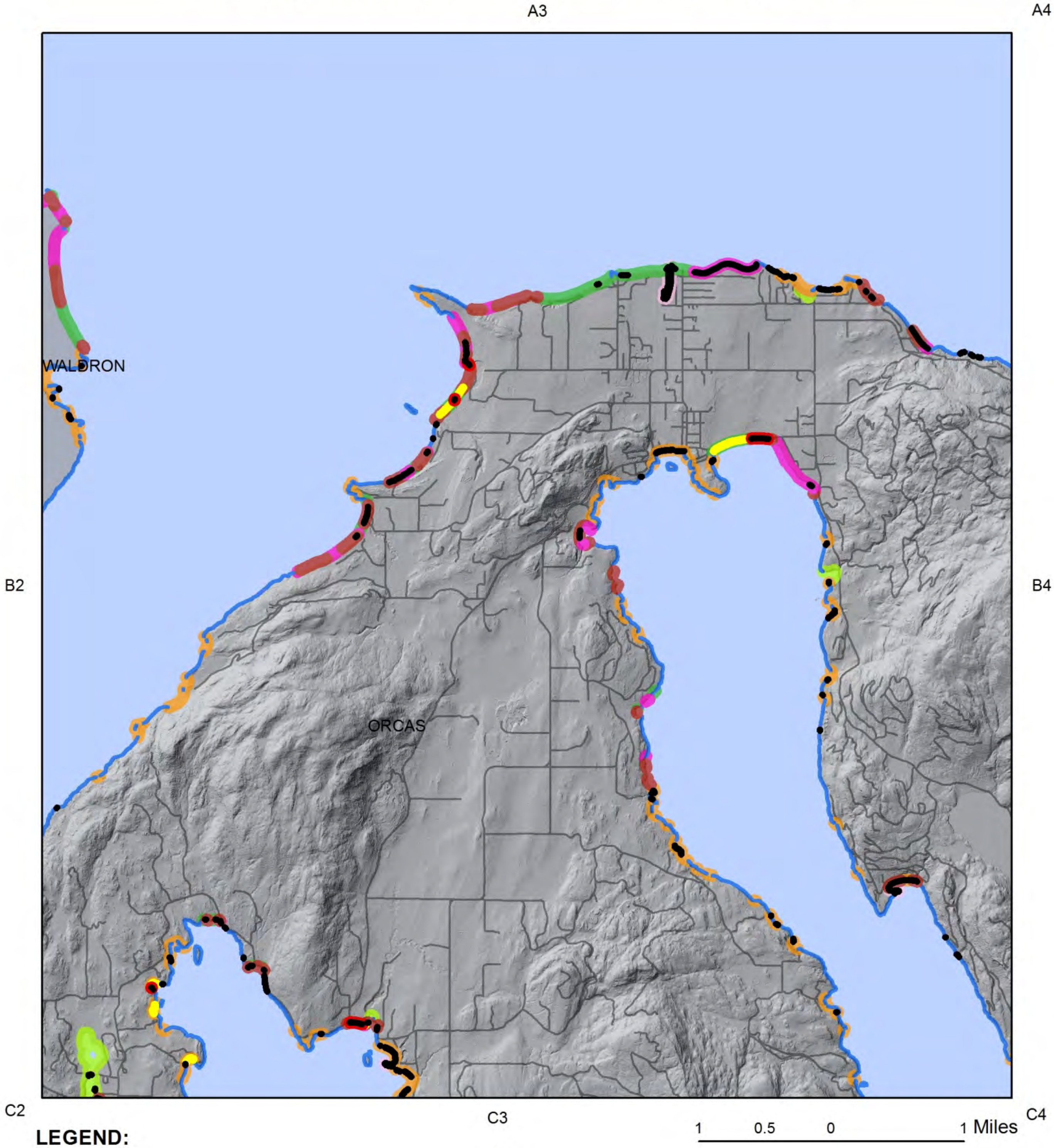
- Artificial
- Barrier Beach
- Embayments - Estuary
- Embayments - Lagoon
- Feeder Bluff
- Pocket Beach
- Rocky Shoreline
- Transport Zone

- Shoreline Armoring
- Documented Surf Smelt & Pacific Sand Lance Spawning Habitat
- Direct Burial-Documented Spawn Site with Armor Toe 9 ft. and below M.L.L.W.
- Roads



B2

Forage Fish and Armor Habitat Impacts



LEGEND:

Shoreform

Artificial
Barrier Beach
Embayments - Estuary
Embayments - Lagoon
Feeder Bluff
Pocket Beach
Rocky Shoreline
Transport Zone

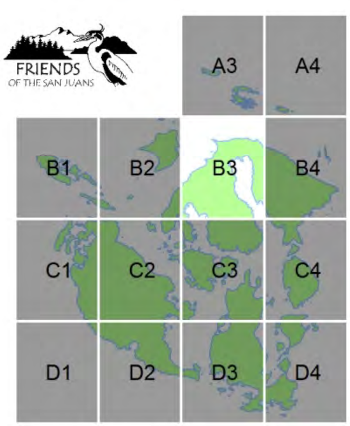
Shoreline Armoring

Documented Surf Smelt & Pacific Sand Lance Spawning Habitat

Direct Burial-Documented Spawn Site with Armor Toe 9 ft. and below M.L.L.W.

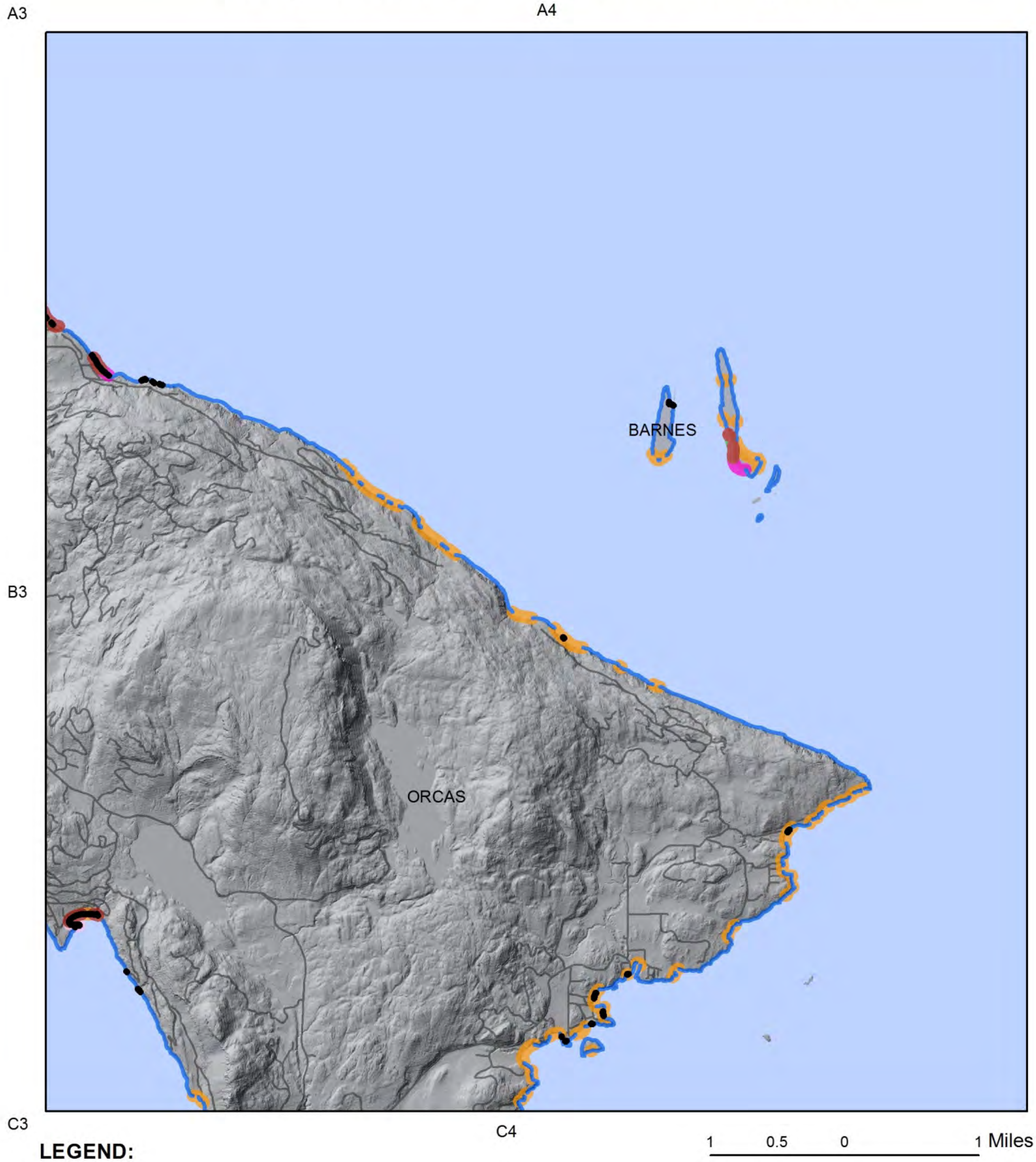
Roads

FRIENDS OF THE SAN JUANS



B3

Forage Fish and Armor Habitat Impacts



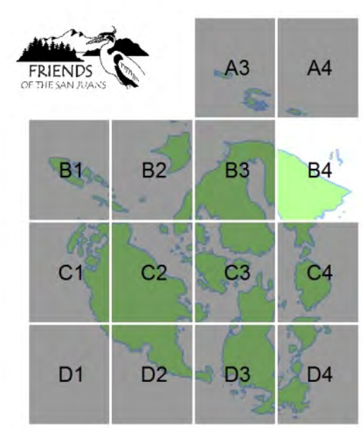
LEGEND:

Shoreform

Artificial
Barrier Beach
Embayments - Estuary
Embayments - Lagoon
Feeder Bluff
Pocket Beach
Rocky Shoreline
Transport Zone

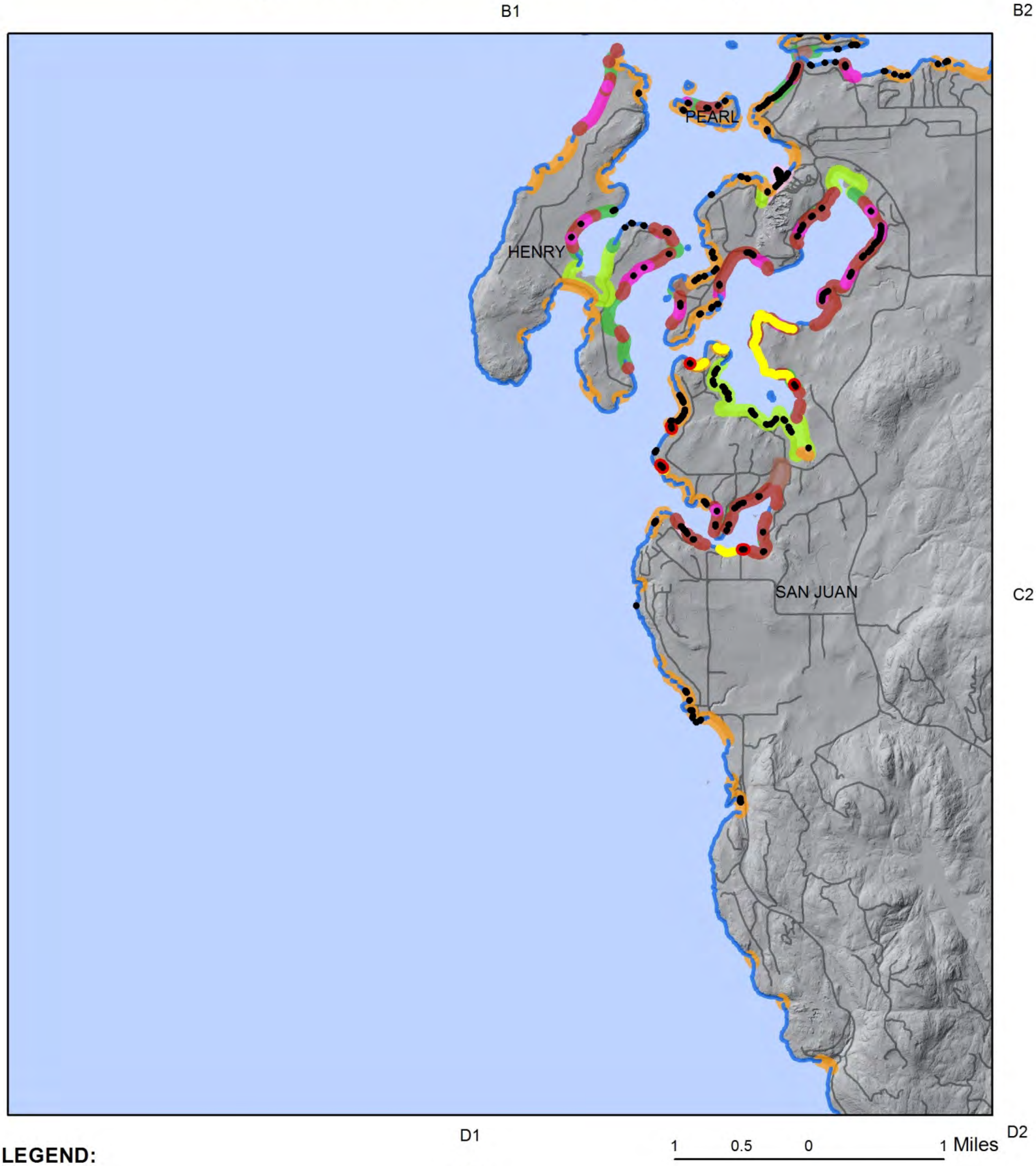
Shoreline Armoring
Documented Surf Smelt & Pacific Sand Lance Spawning Habitat
Direct Burial-Documented Spawn Site with Armor Toe 9 ft. and below M.L.L.W.
Roads

N



B4

Forage Fish and Armor Habitat Impacts



LEGEND:

Shoreform

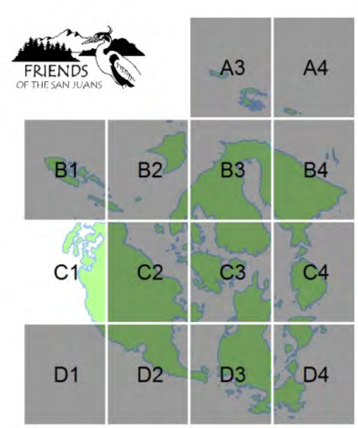
Artificial
Barrier Beach
Embayments - Estuary
Embayments - Lagoon
Feeder Bluff
Pocket Beach
Rocky Shoreline
Transport Zone

Shoreline Armoring

Documented Surf Smelt & Pacific Sand Lance Spawning Habitat

Direct Burial-Documented Spawn Site with Armor Toe 9 ft. and below M.L.L.W.

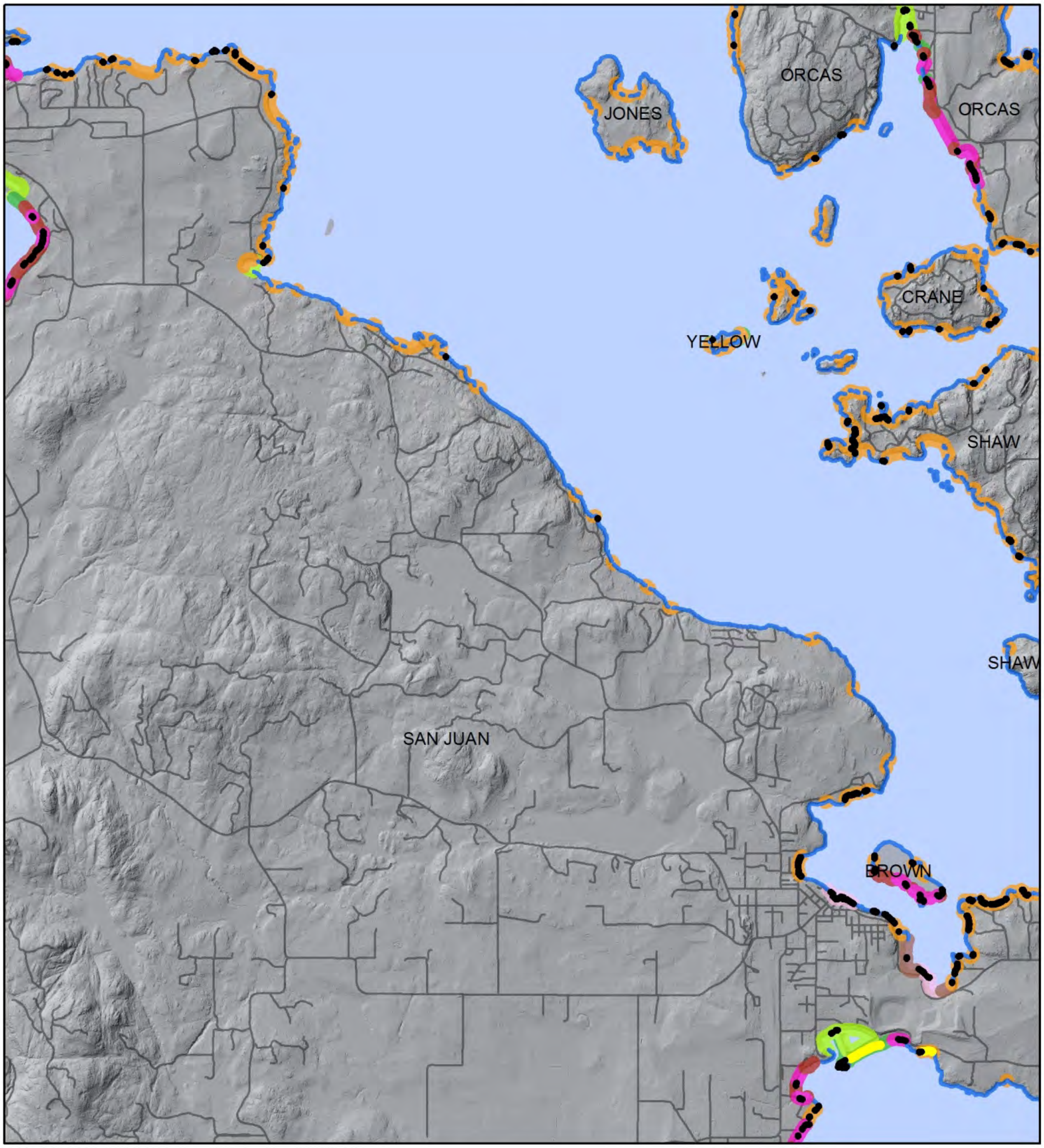
Roads



C1

Forage Fish and Armor Habitat Impacts

B1 B2 B3



C1 C3

D1 D2 D3

1 0.5 0 1 Miles

LEGEND:

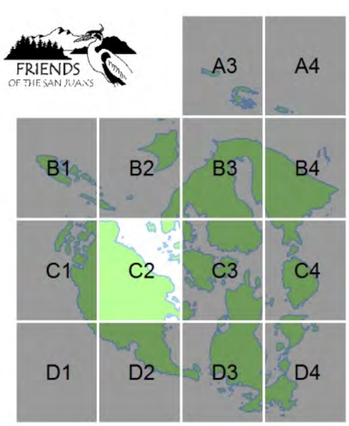
Shoreform

- Artificial
- Barrier Beach
- Embayments - Estuary
- Embayments - Lagoon
- Feeder Bluff
- Pocket Beach
- Rocky Shoreline
- Transport Zone

- Shoreline Armoring
- Documented Surf Smelt & Pacific Sand Lance Spawning Habitat
- Direct Burial-Documented Spawn Site with Armor Toe 9 ft. and below M.L.L.W.
- Roads

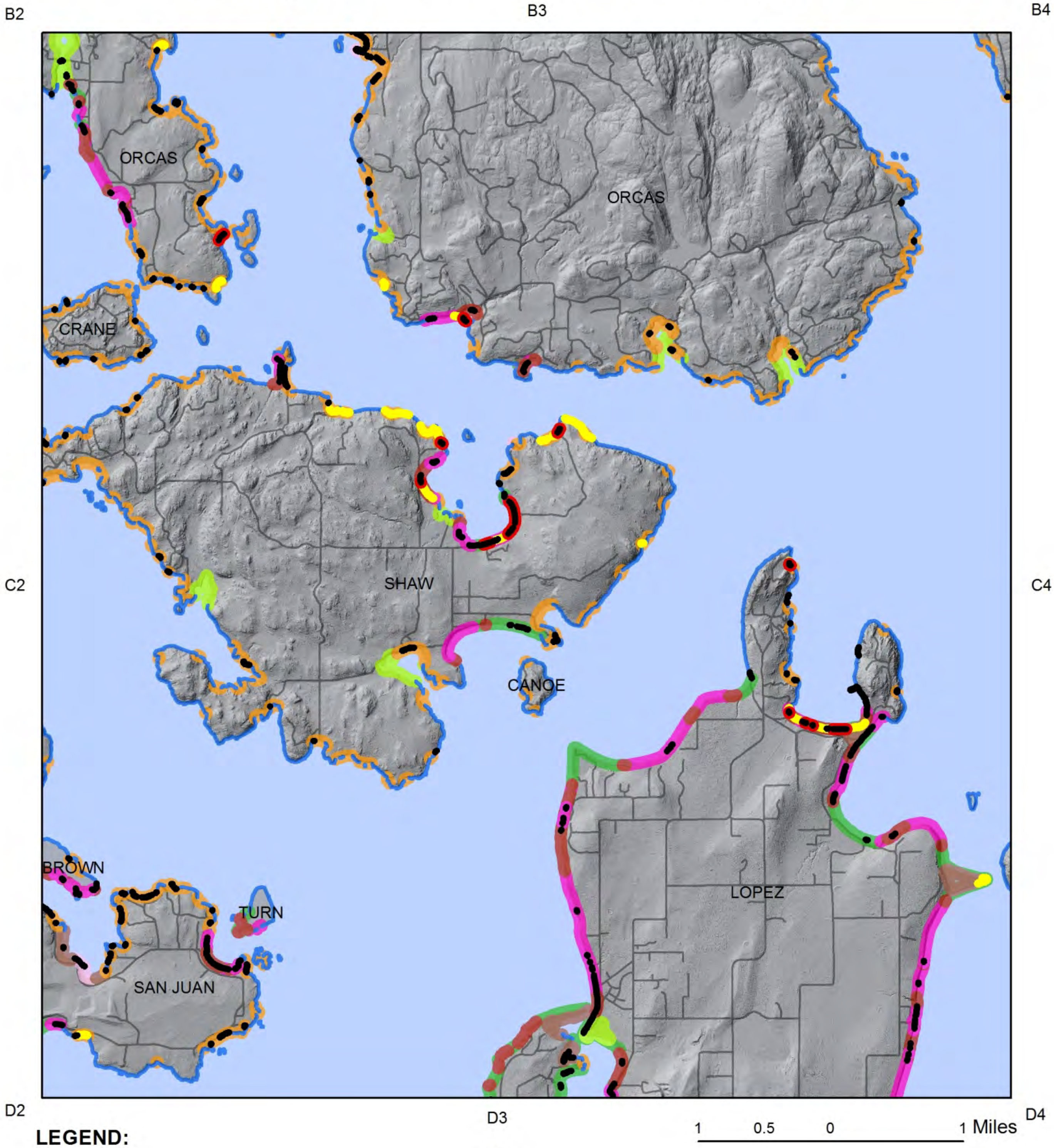
N

FRIENDS OF THE SAN JUANS



C2

Forage Fish and Armor Habitat Impacts

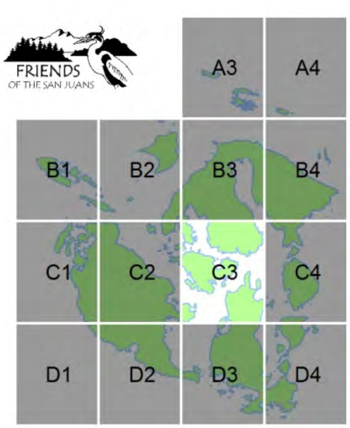


LEGEND:

Shoreform

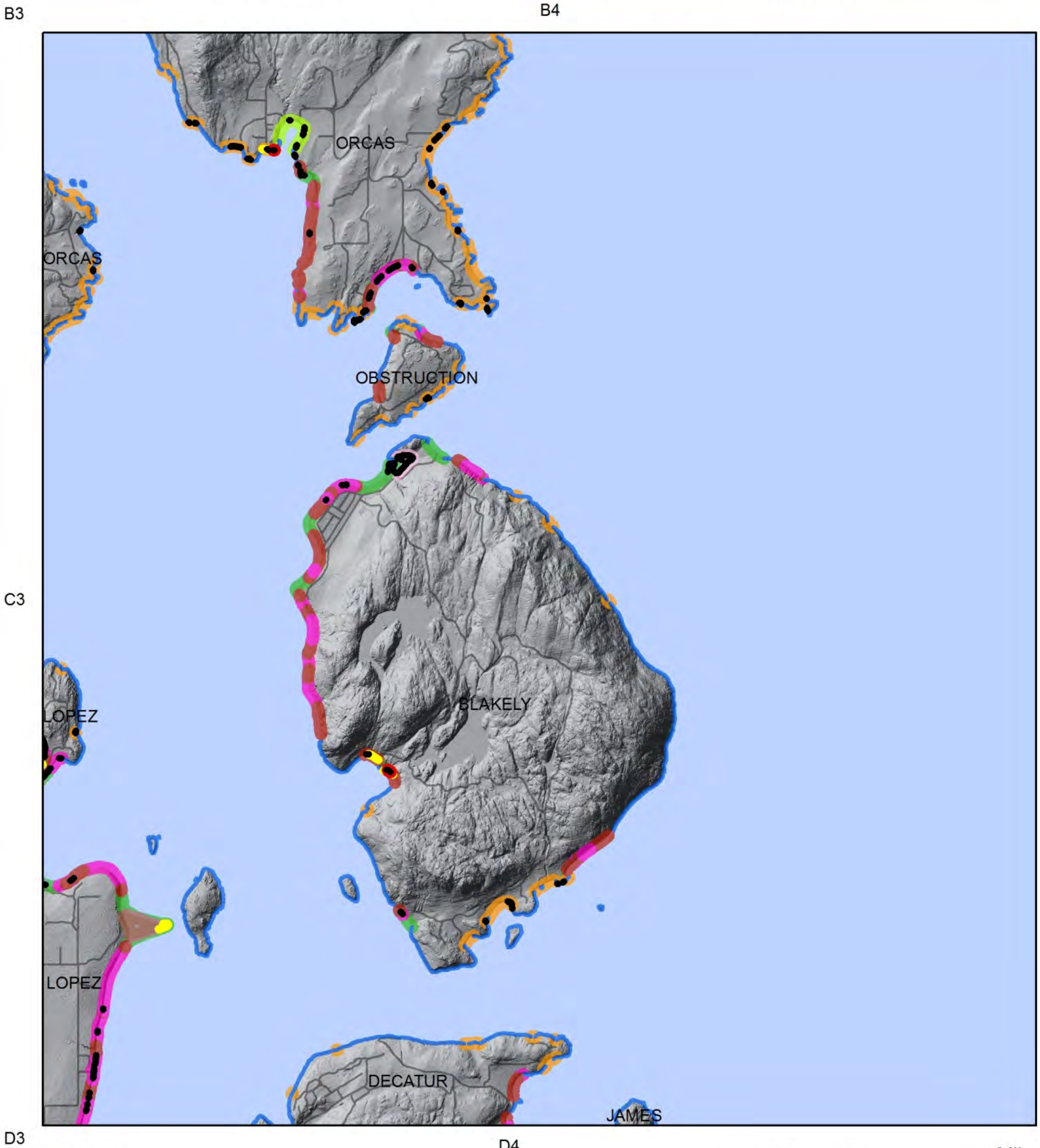
Artificial
Barrier Beach
Embayments - Estuary
Embayments - Lagoon
Feeder Bluff
Pocket Beach
Rocky Shoreline
Transport Zone

Shoreline Armoring
Documented Surf Smelt & Pacific Sand Lance Spawning Habitat
Direct Burial-Documented Spawn Site with Armor Toe 9 ft. and below M.L.L.W.
Roads



C3

Forage Fish and Armor Habitat Impacts



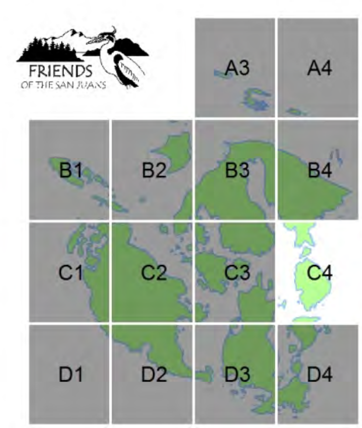
LEGEND:

Shoreform

Artificial
Barrier Beach
Embayments - Estuary
Embayments - Lagoon
Feeder Bluff
Pocket Beach
Rocky Shoreline
Transport Zone

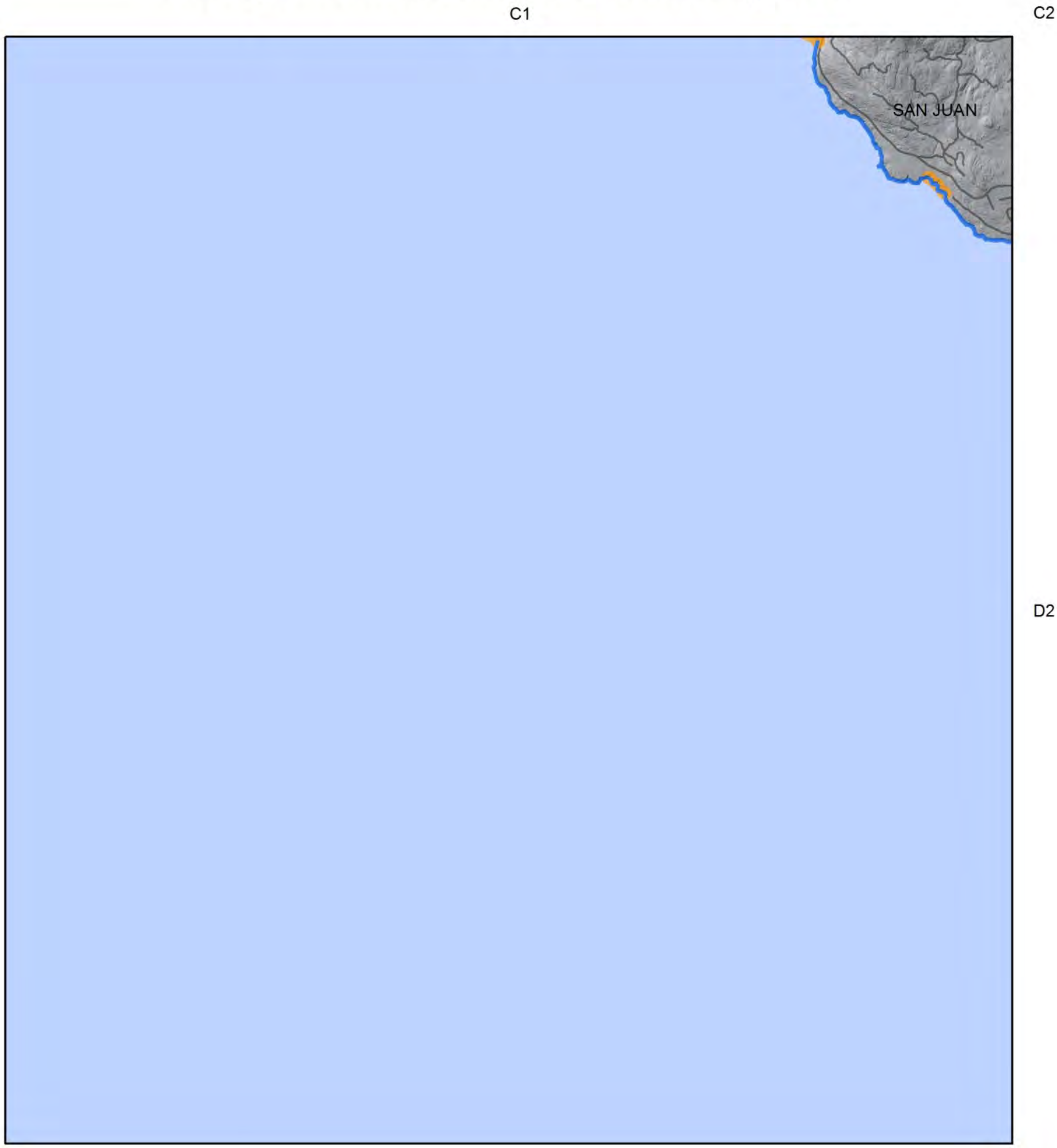
Shoreline Armoring
Documented Surf Smelt & Pacific Sand Lance Spawning Habitat
Direct Burial-Documented Spawn Site with Armor Toe 9 ft. and below M.L.L.W.
Roads

N



C4

Forage Fish and Armor Habitat Impacts



1 0.5 0 1 Miles

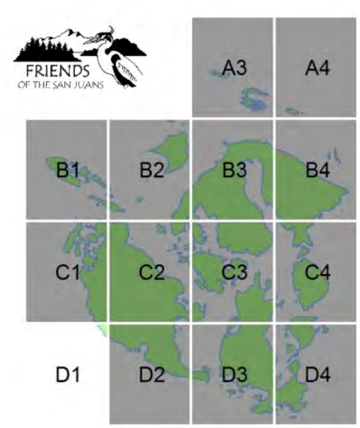
LEGEND:

Shoreform

- Artificial
- Barrier Beach
- Embayments - Estuary
- Embayments - Lagoon
- Feeder Bluff
- Pocket Beach
- Rocky Shoreline
- Transport Zone

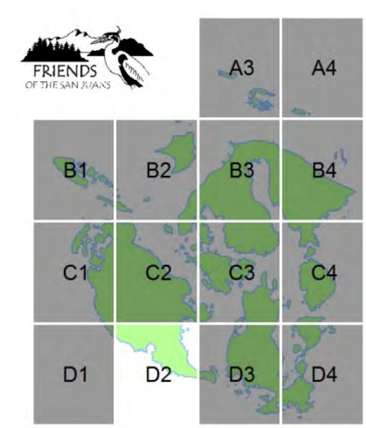
- Shoreline Armoring
- Documented Surf Smelt & Pacific Sand Lance Spawning Habitat
- Direct Burial-Documented Spawn Site with Armor Toe 9 ft. and below M.L.L.W.
- Roads

N



D1

Forage Fish and Armor Habitat Impacts



LEGEND:

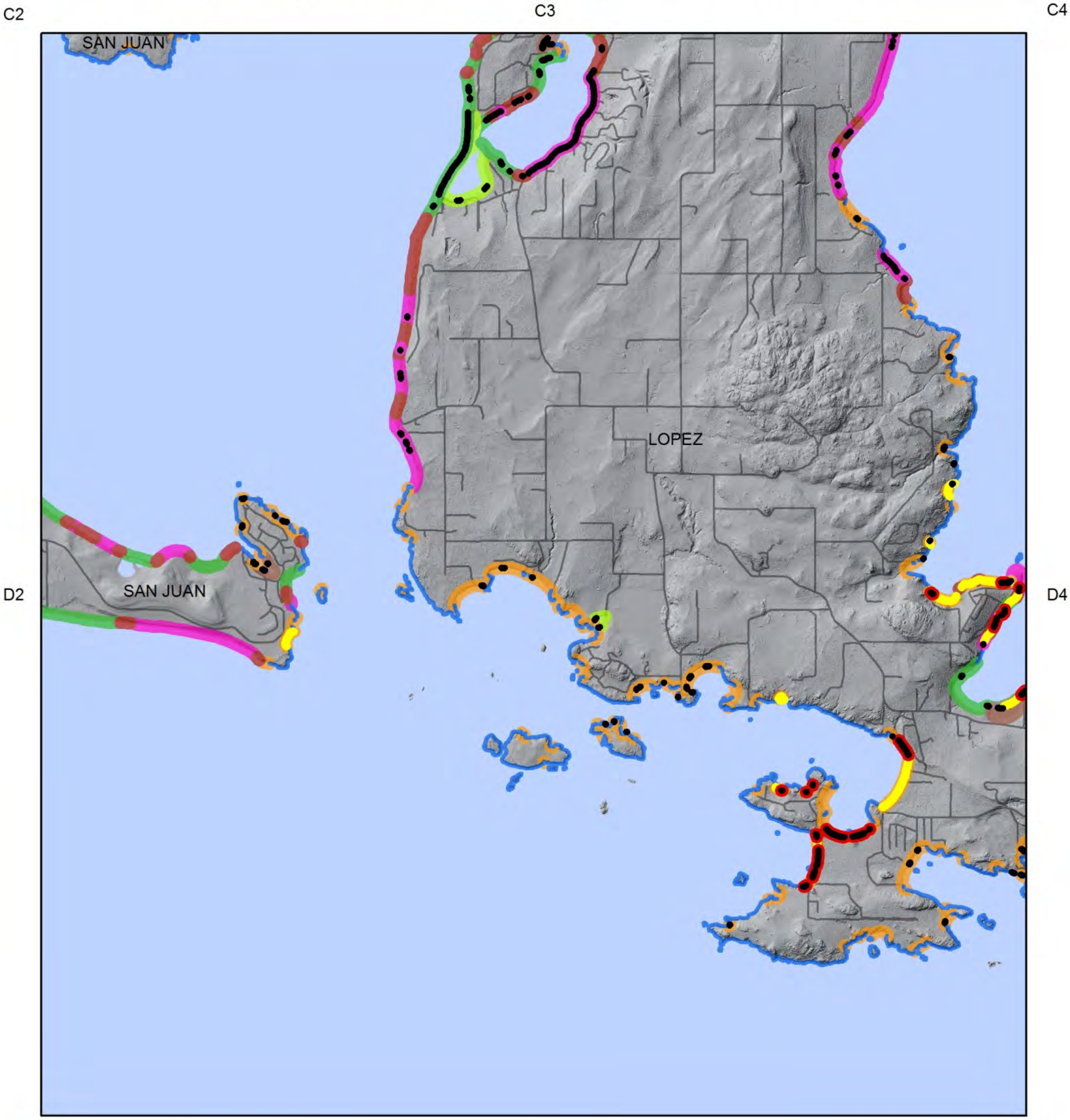
Shoreform

- Artificial
- Barrier Beach
- Embayments - Estuary
- Embayments - Lagoon
- Feeder Bluff
- Pocket Beach
- Rocky Shoreline
- Transport Zone

- Shoreline Armoring
- Documented Surf Smelt & Pacific Sand Lance Spawning Habitat
- Direct Burial-Documented Spawn Site with Armor Toe 9 ft. and below M.L.L.W.
- Roads

D2

Forage Fish and Armor Habitat Impacts



1 0.5 0 1 Miles

LEGEND:

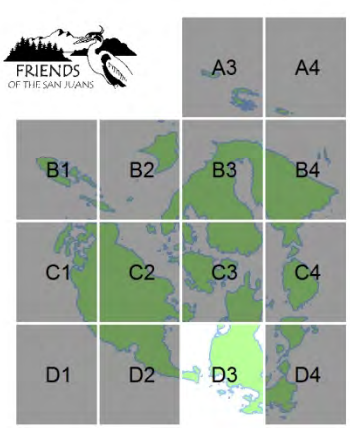
N

Shoreform

Artificial
Barrier Beach
Embayments - Estuary
Embayments - Lagoon
Feeder Bluff
Pocket Beach
Rocky Shoreline
Transport Zone

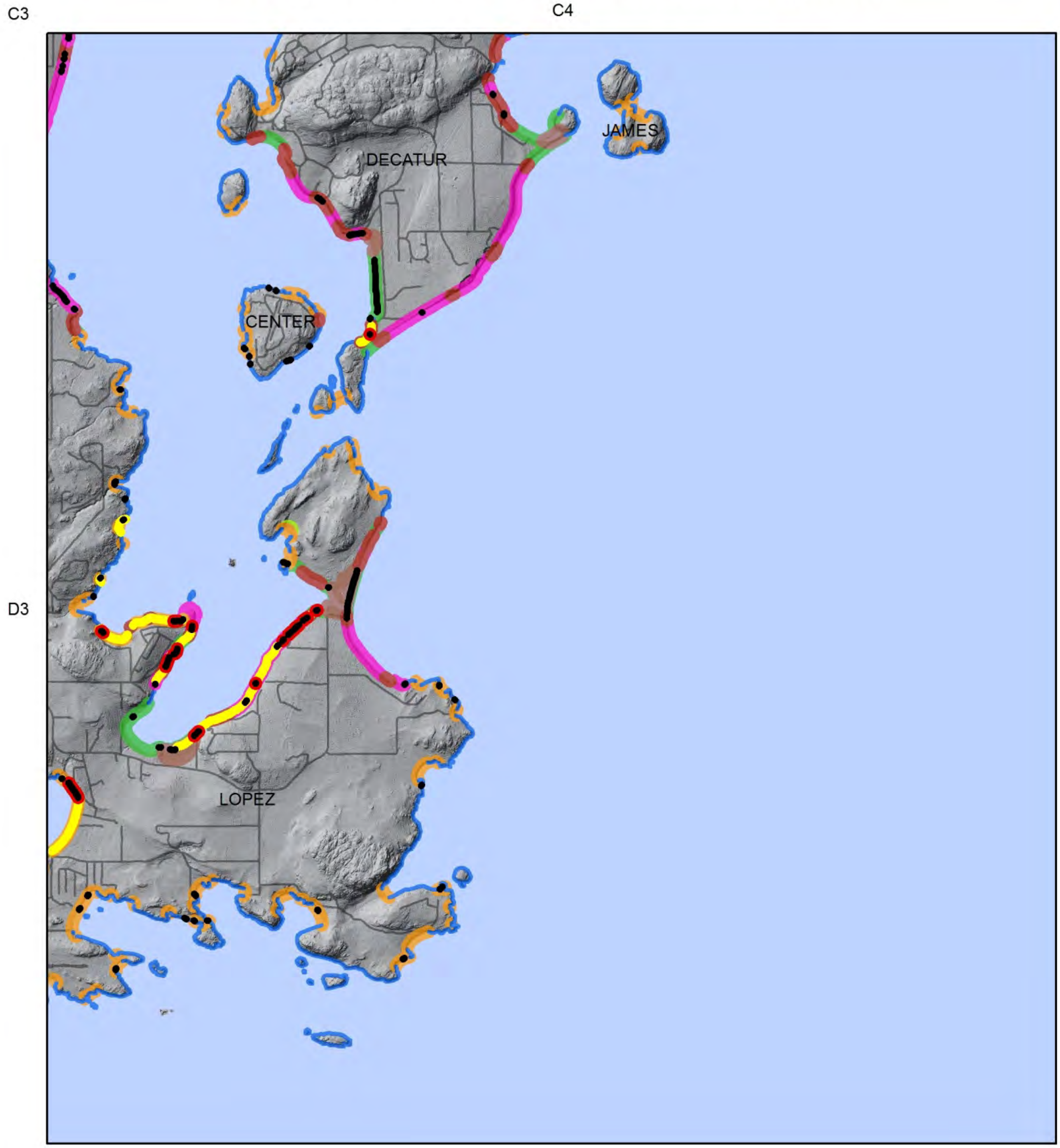
Shoreline Armoring
Documented Surf Smelt & Pacific Sand Lance Spawning Habitat
Direct Burial-Documented Spawn Site with Armor Toe 9 ft. and below M.L.L.W.
Roads

FRIENDS OF THE SAN JUANS



D3

Forage Fish and Armor Habitat Impacts



LEGEND:

Shoreform

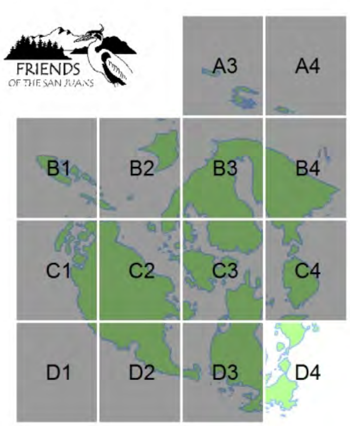
Artificial
Barrier Beach
Embayments - Estuary
Embayments - Lagoon
Feeder Bluff
Pocket Beach
Rocky Shoreline
Transport Zone

Shoreline Armoring
Documented Surf Smelt & Pacific Sand Lance Spawning Habitat
Direct Burial-Documented Spawn Site with Armor Toe 9 ft. and below M.L.L.W.
Roads

N

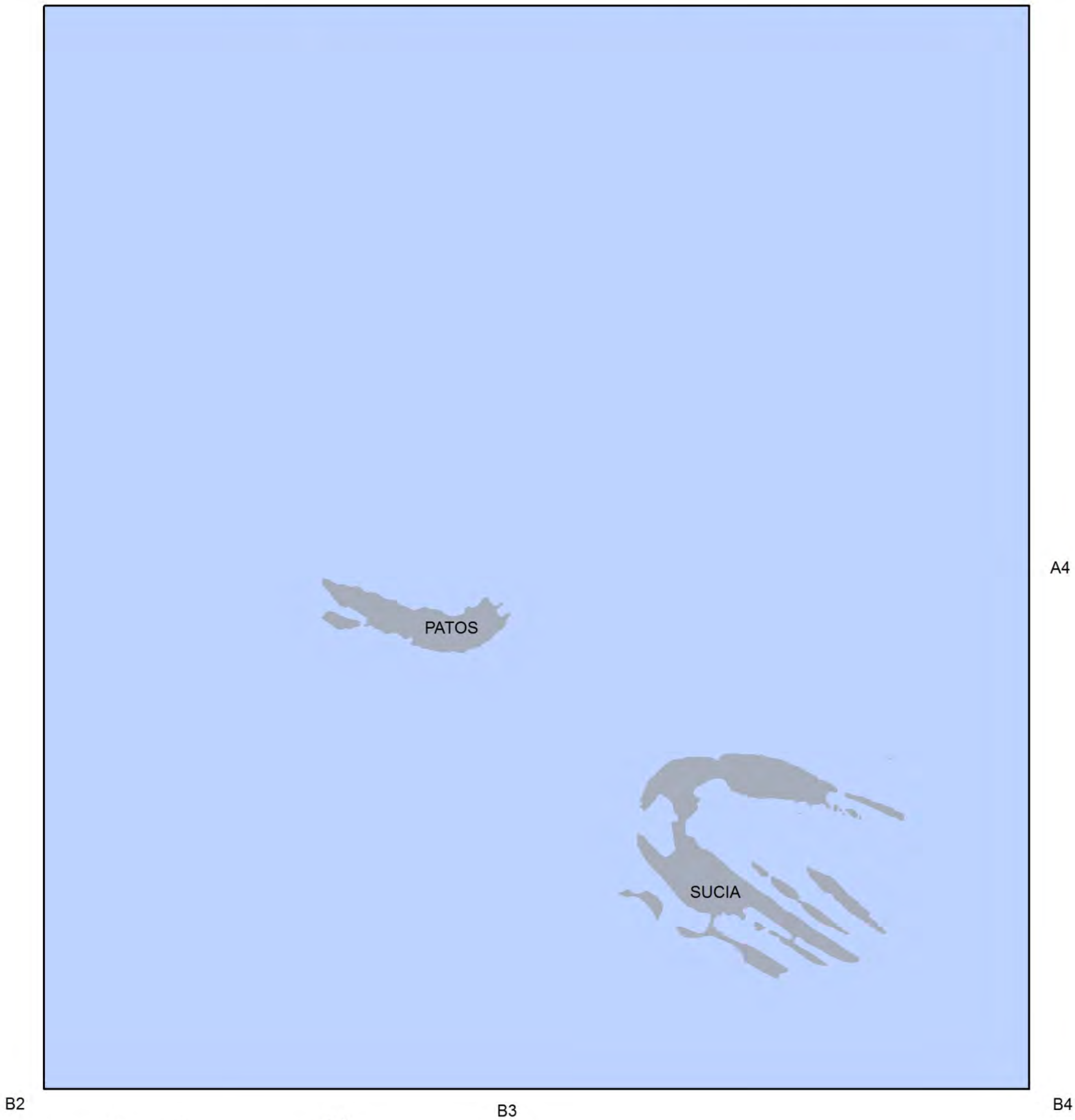
1 0.5 0 1 Miles

FRIENDS OF THE SAN JUANS



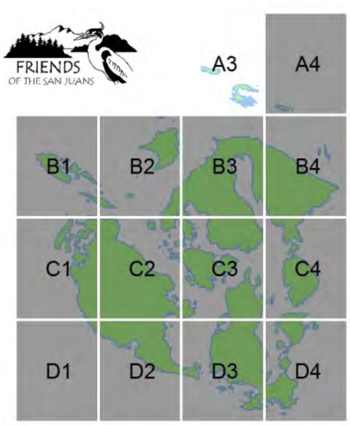
D4

Forage Fish and Armor Process Impacts



1 0.5 0 1 Miles

N



LEGEND:

Documented Surf Smelt & Pacific Sand Lance Spawning Habitat

Impact to Sediment Supply-Armored Feeder Bluff

Impact to Sediment Transport-All Armor-Toe 4.5 ft. M.L.L.W.and Below

Drift Cells

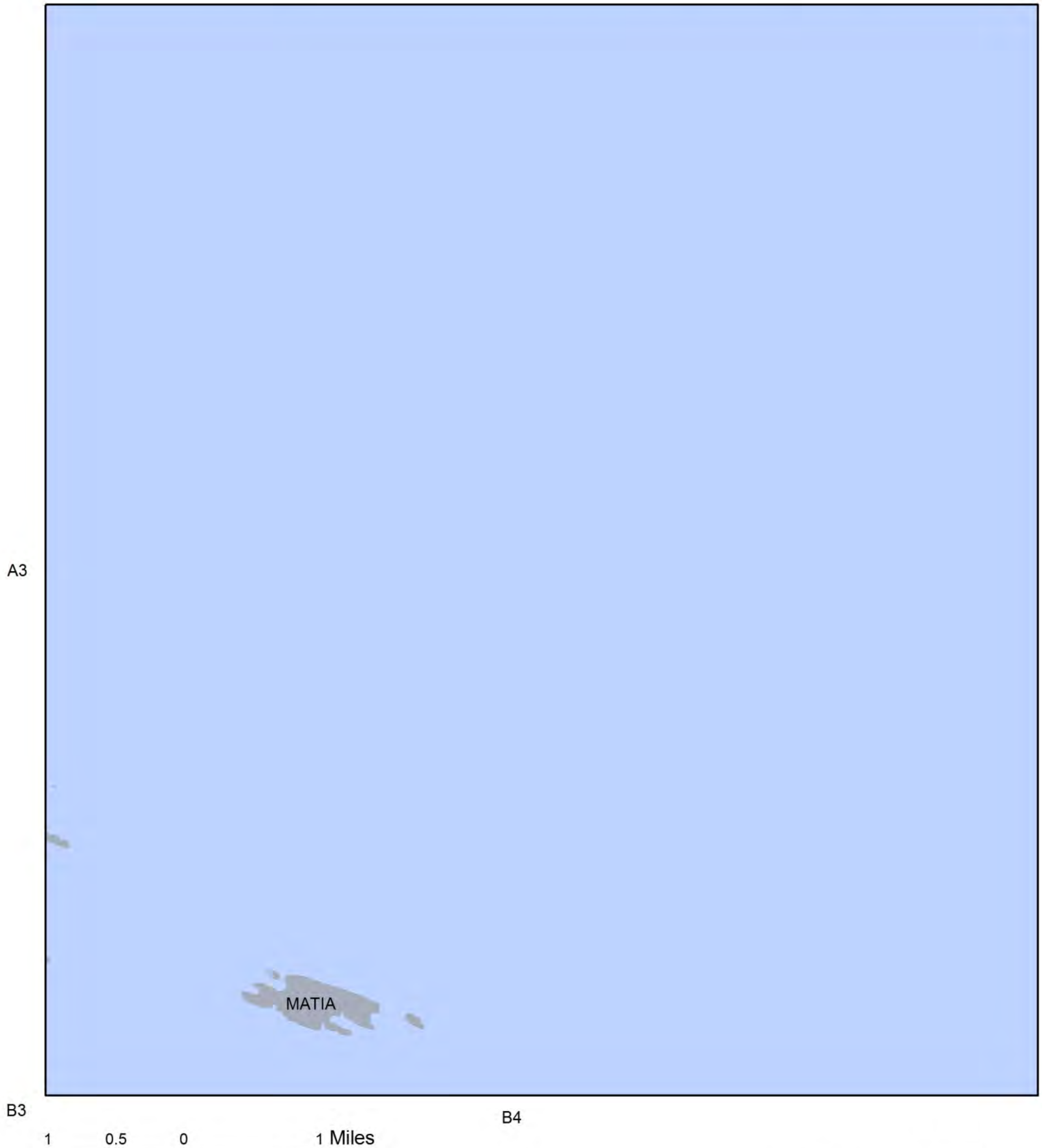
Direction of Drift

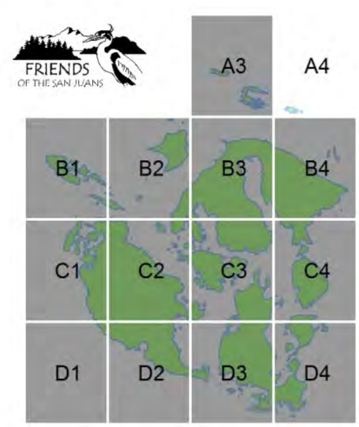
Left to Right

Right to Left

A3

Forage Fish and Armor Process Impacts





LEGEND:

- Documented Surf Smelt & Pacific Sand Lance Spawning Habitat
- Impact to Sediment Supply-Armored Feeder Bluff
- Impact to Sediment Transport-All Armor-Toe 4.5 ft. M.L.L.W.and Below

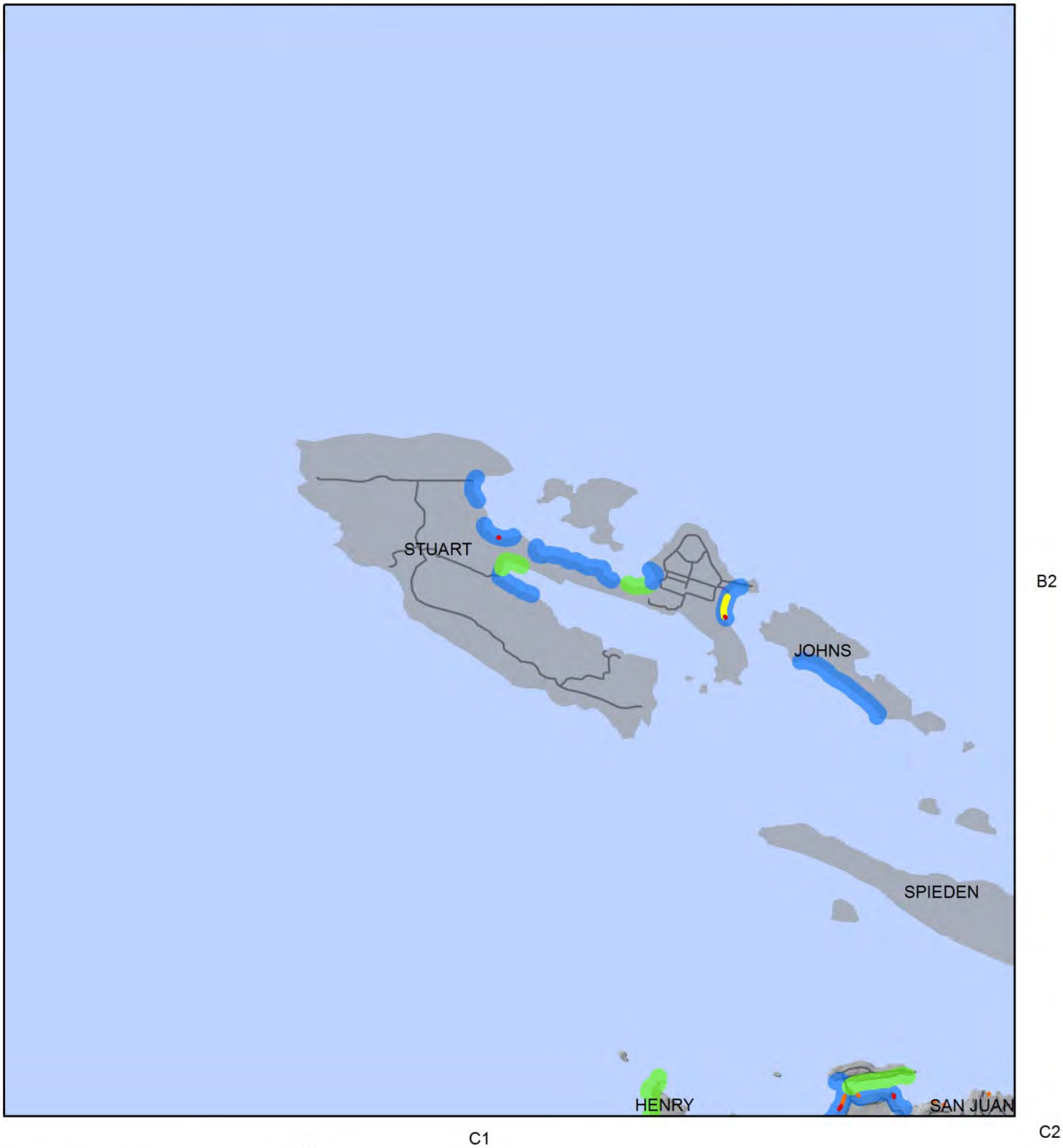
Drift Cells

Direction of Drift

- Left to Right
- Right to Left

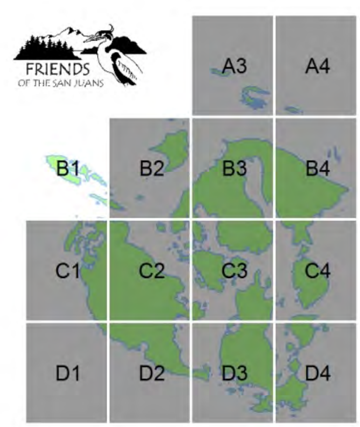
A4

Forage Fish and Armor Process Impacts



1 0.5 0 1 Miles

N



LEGEND:

- Documented Surf Smelt & Pacific Sand Lance Spawning Habitat
- Impact to Sediment Supply-Armored Feeder Bluff
- Impact to Sediment Transport-All Armor-Toe 4.5 ft. M.L.L.W.and Below

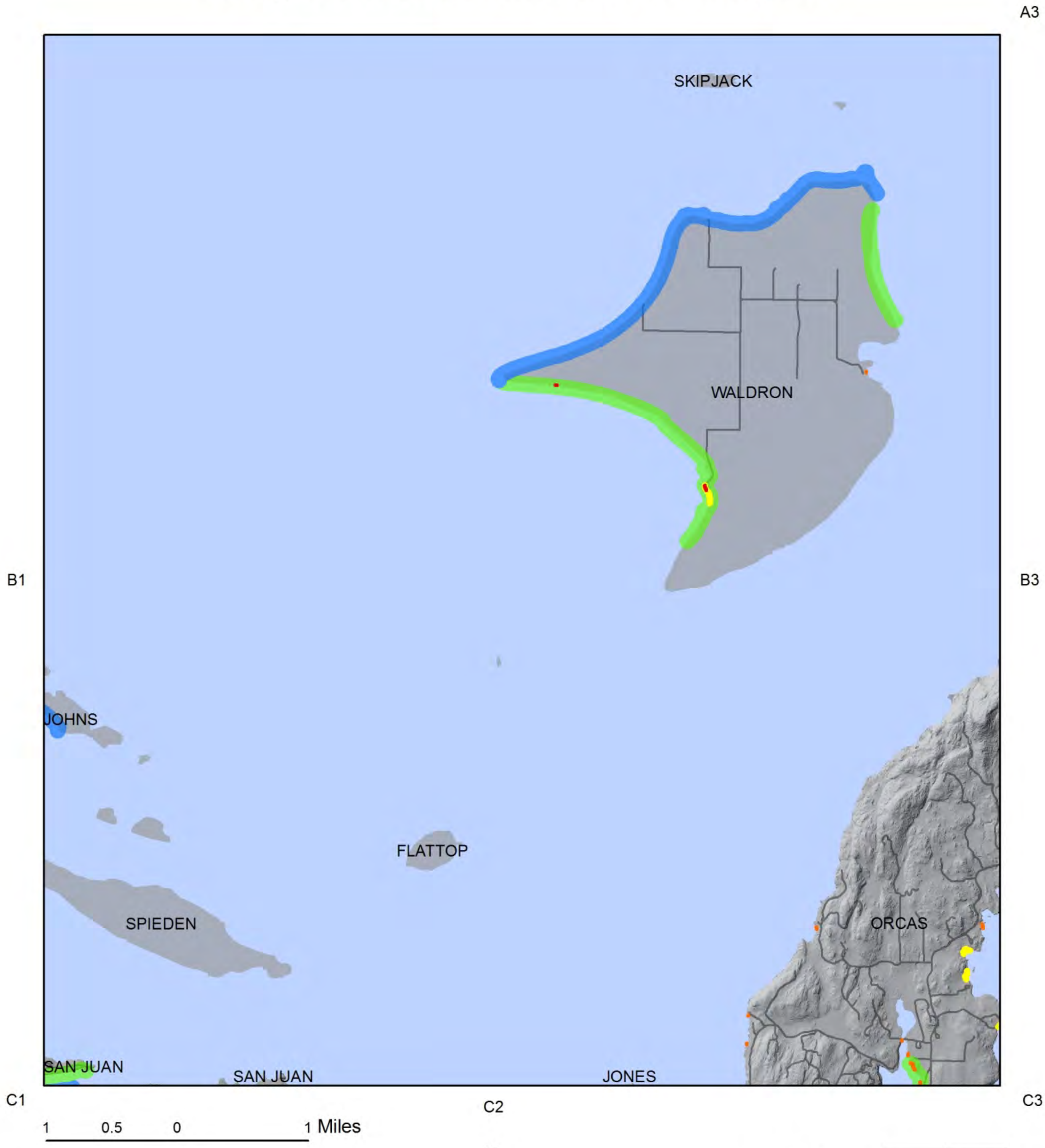
Drift Cells

Direction of Drift

- Left to Right
- Right to Left

B1

Forage Fish and Armor Process Impacts



LEGEND:

Documented Surf Smelt & Pacific Sand Lance Spawning Habitat

Impact to Sediment Supply-Armored Feeder Bluff

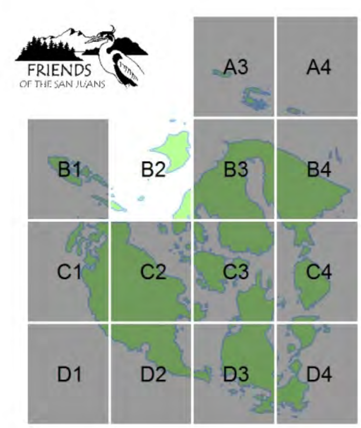
Impact to Sediment Transport-All Armor-Toe 4.5 ft. M.L.L.W.and Below

Drift Cells

Direction of Drift

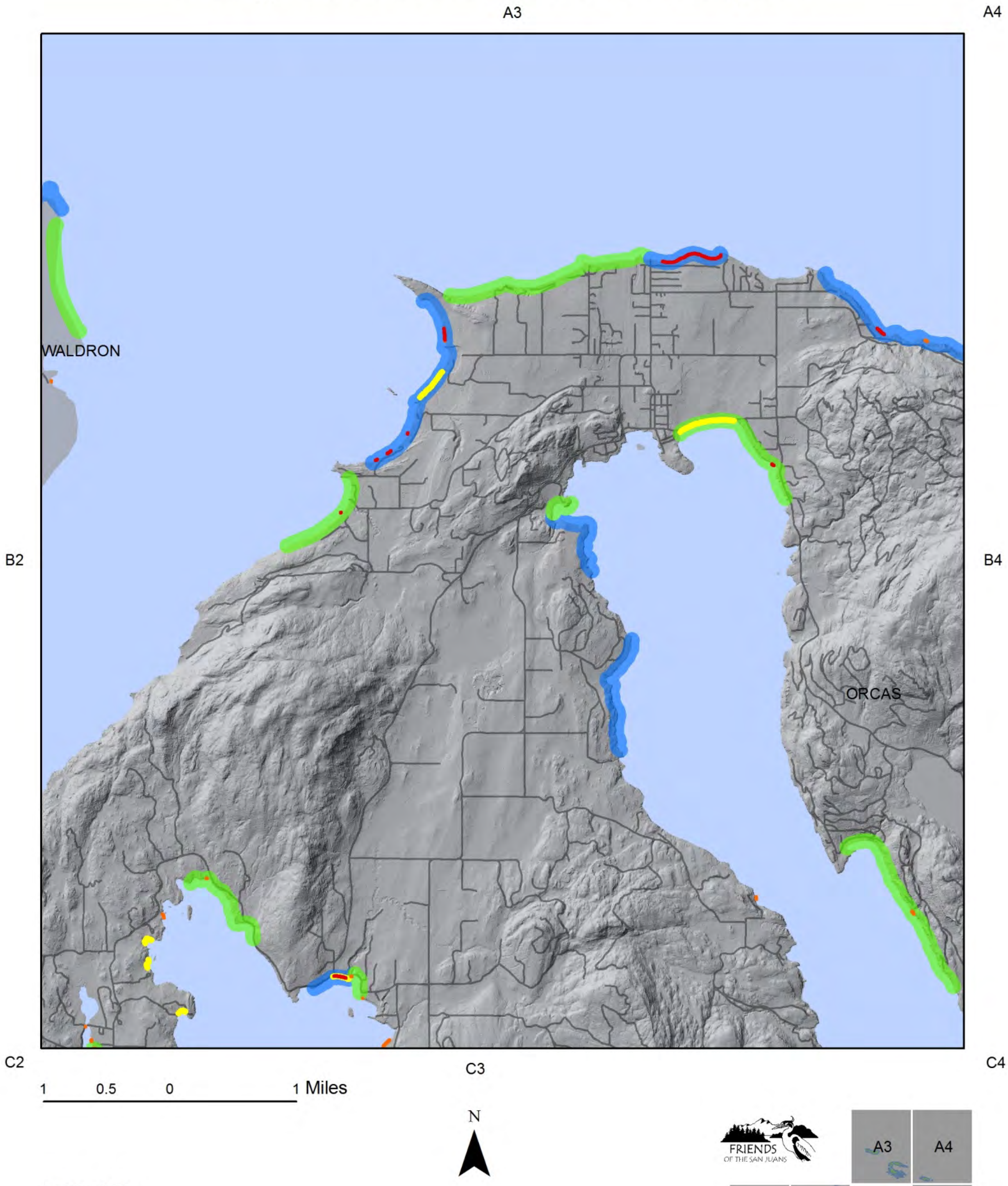
Left to Right

Right to Left



B2

Forage Fish and Armor Process Impacts



LEGEND:

Documented Surf Smelt & Pacific Sand Lance Spawning Habitat

Impact to Sediment Supply-Armored Feeder Bluff

Impact to Sediment Transport-All Armor-Toe 4.5 ft. M.L.L.W.and Below

Drift Cells

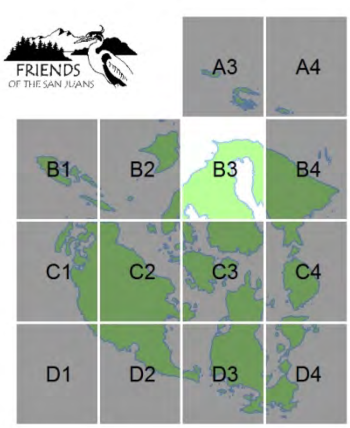
Direction of Drift

Left to Right

Right to Left

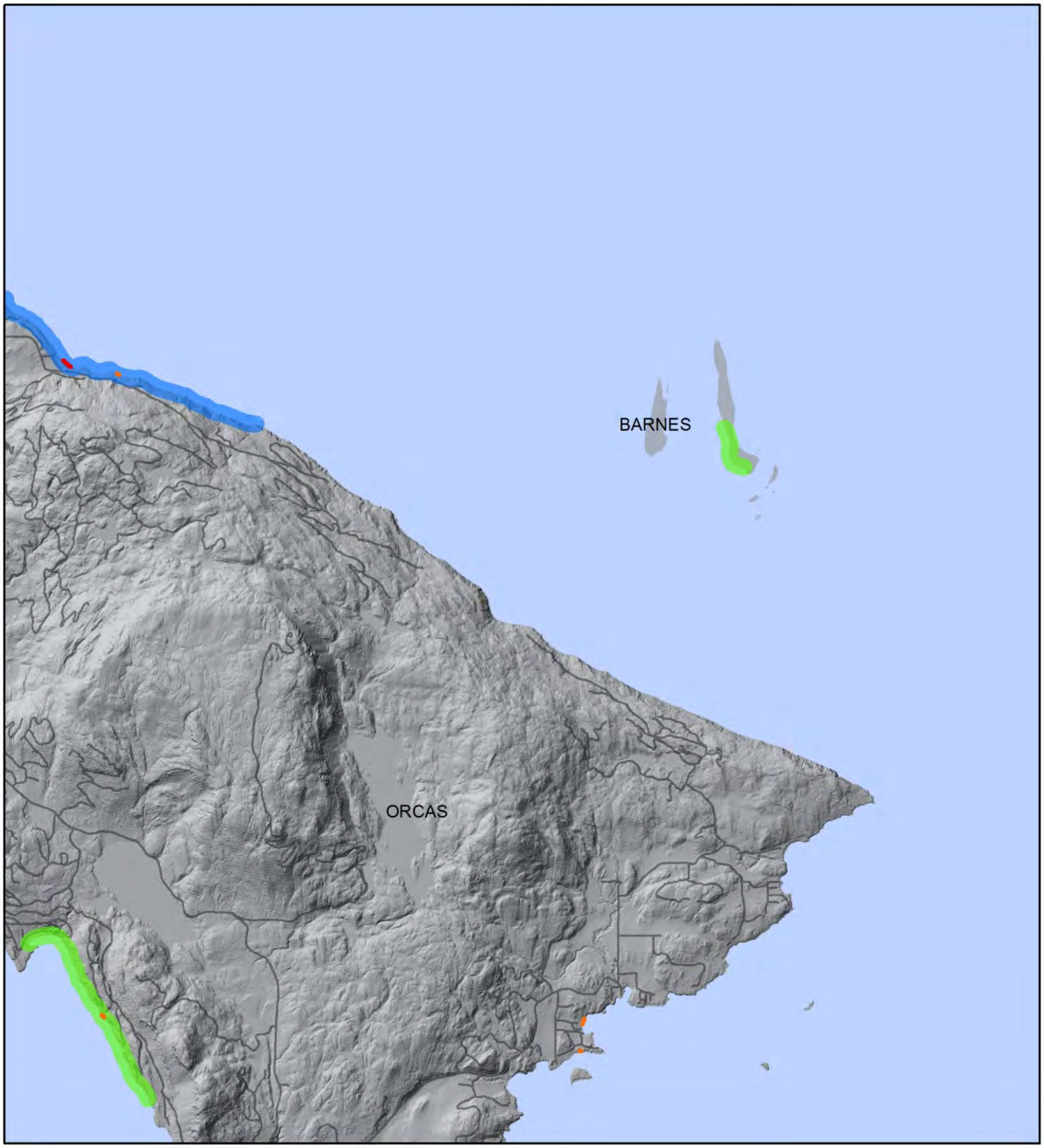
B3

FRIENDS OF THE SAN JUANS



Forage Fish and Armor Process Impacts

A3 A4



B3

C3 C4

1 0.5 0 1 Miles

N

LEGEND:

- Documented Surf Smelt & Pacific Sand Lance Spawning Habitat
- Impact to Sediment Supply-Armored Feeder Bluff
- Impact to Sediment Transport-All Armor-Toe 4.5 ft. M.L.L.W.and Below

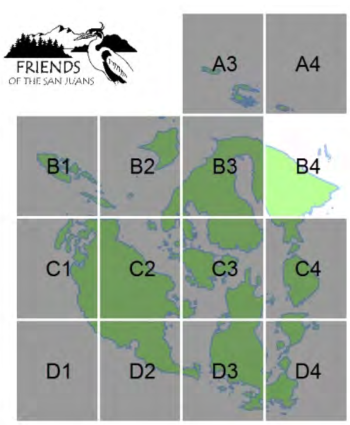
Drift Cells

Direction of Drift

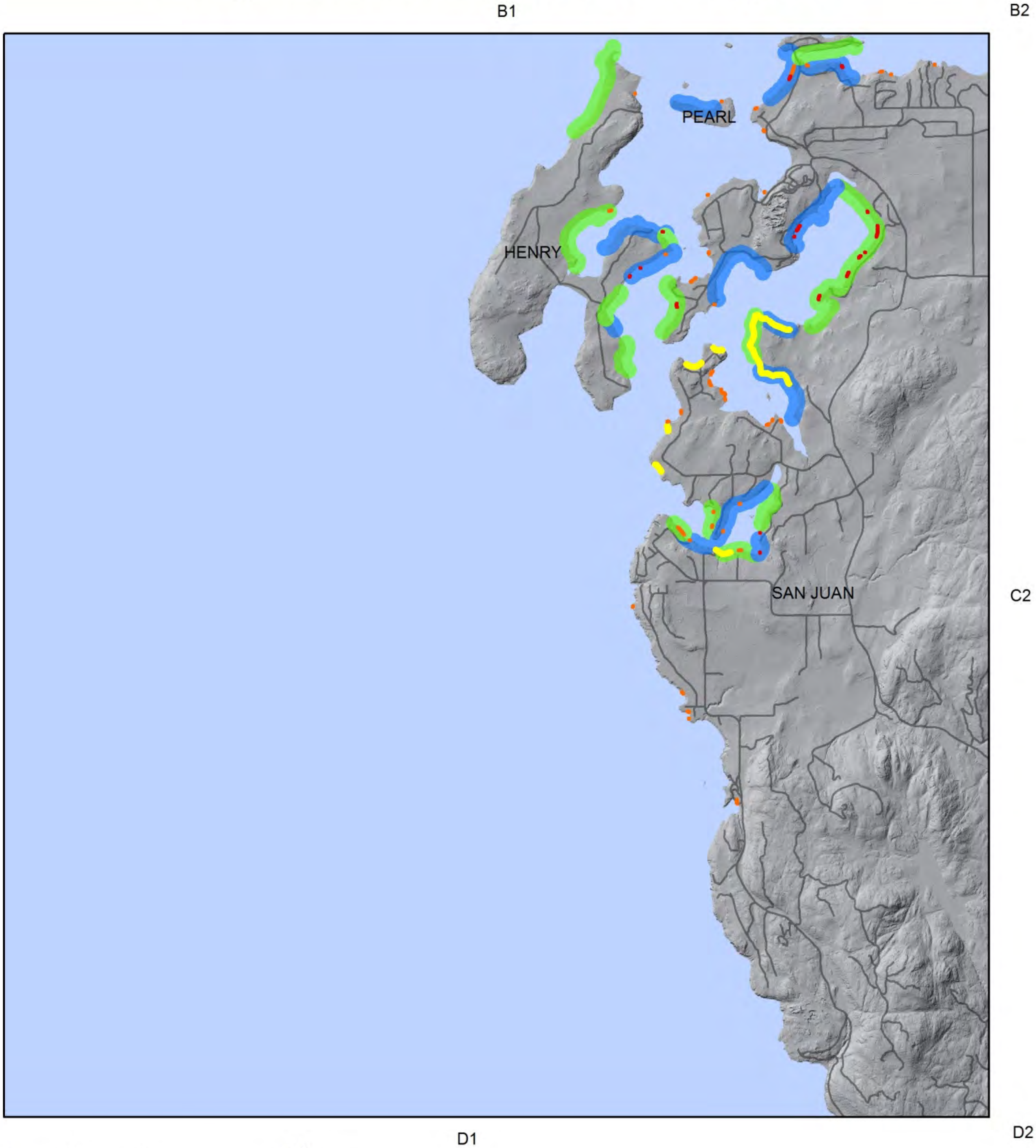
- Left to Right
- Right to Left

B4

FRIENDS OF THE SAN JUANS



Forage Fish and Armor Process Impacts



1 0.5 0 1 Miles

N

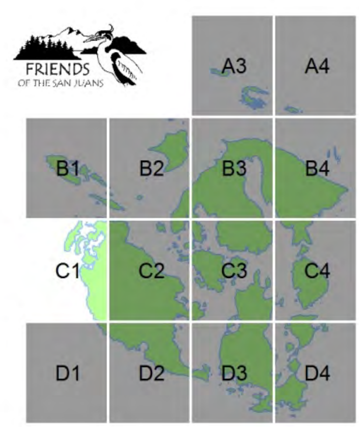
LEGEND:

- Documented Surf Smelt & Pacific Sand Lance Spawning Habitat
- Impact to Sediment Supply-Armored Feeder Bluff
- Impact to Sediment Transport-All Armor-Toe 4.5 ft. M.L.L.W.and Below

Drift Cells

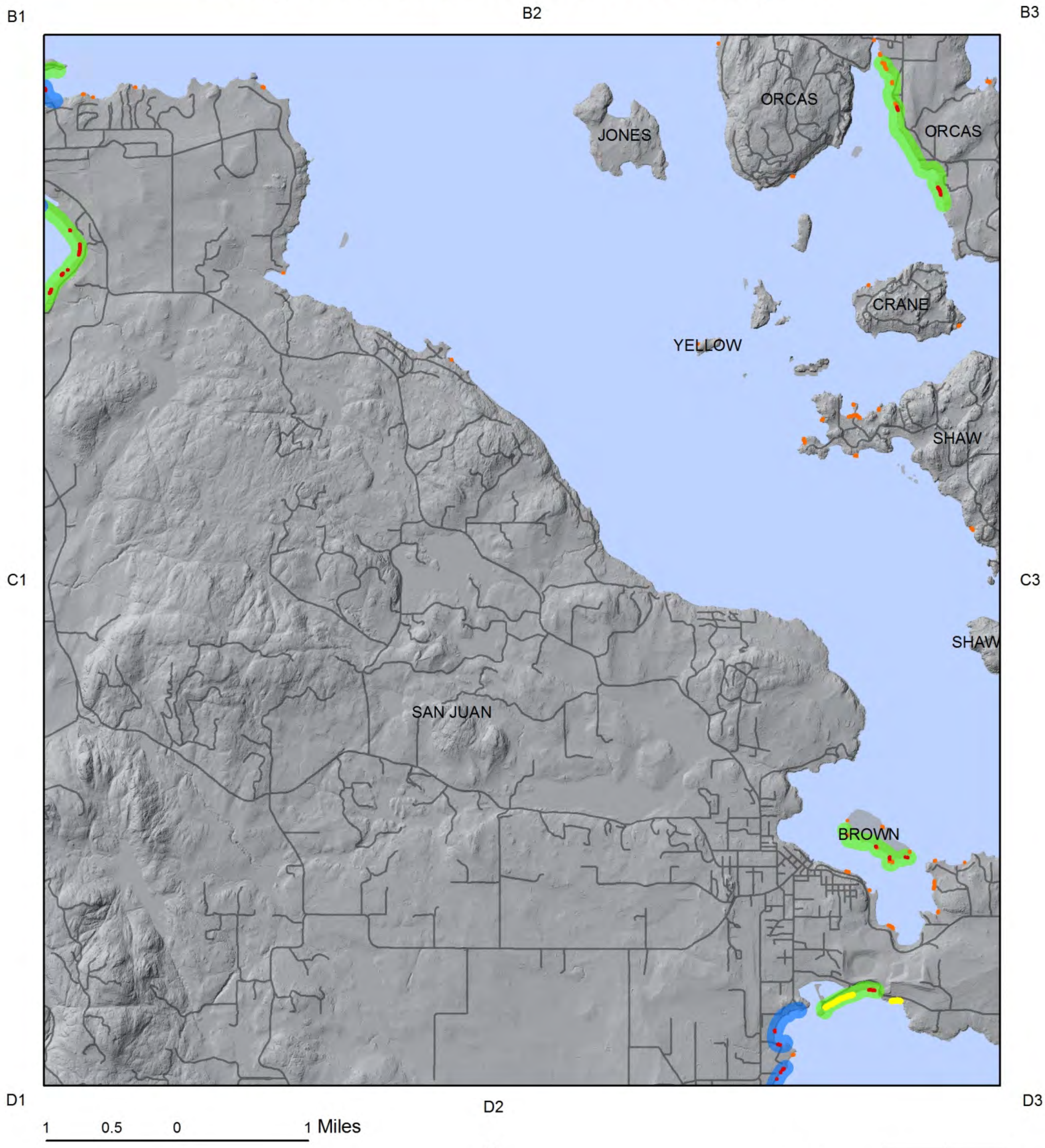
Direction of Drift

- Left to Right
- Right to Left



C1

Forage Fish and Armor Process Impacts



LEGEND:

Documented Surf Smelt & Pacific Sand Lance Spawning Habitat

Impact to Sediment Supply-Armored Feeder Bluff

Impact to Sediment Transport-All Armor-Toe 4.5 ft. M.L.L.W.and Below

Drift Cells

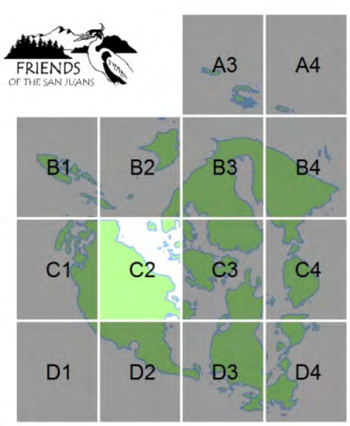
Direction of Drift

Left to Right

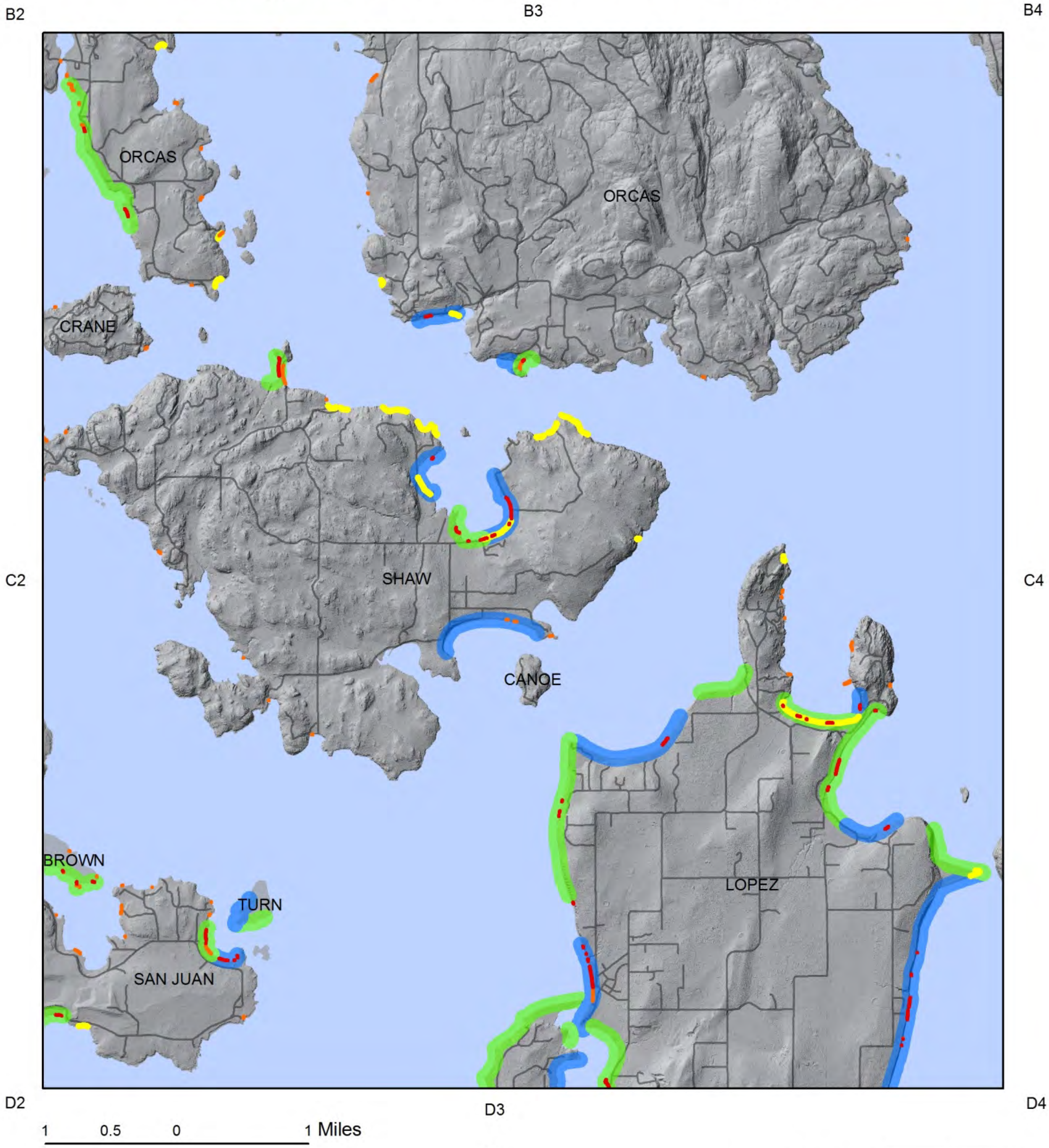
Right to Left

FRIENDS OF THE SAN JUANS

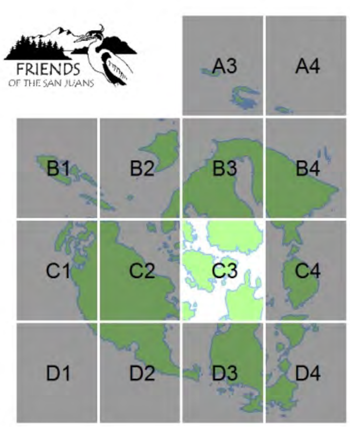
C2



Forage Fish and Armor Process Impacts



N



LEGEND:

- Documented Surf Smelt & Pacific Sand Lance Spawning Habitat
- Impact to Sediment Supply-Armored Feeder Bluff
- Impact to Sediment Transport-All Armor-Toe 4.5 ft. M.L.L.W.and Below

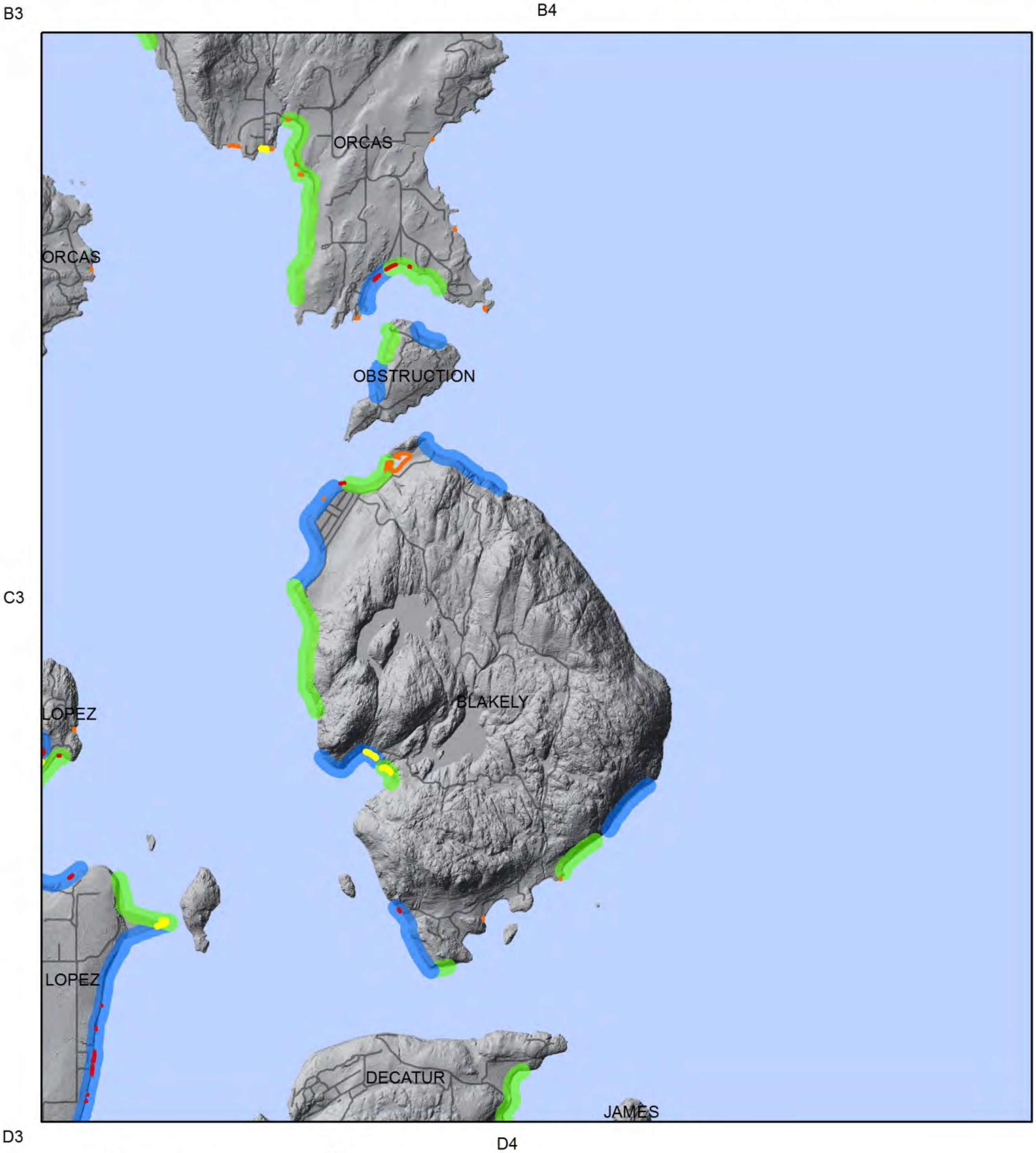
Drift Cells

Direction of Drift

- Left to Right
- Right to Left

C3

Forage Fish and Armor Process Impacts



1 0.5 0 1 Miles

N

LEGEND:

Documented Surf Smelt & Pacific Sand Lance Spawning Habitat
Impact to Sediment Supply-Armored Feeder Bluff
Impact to Sediment Transport-All Armor-Toe 4.5 ft. M.L.L.W.and Below

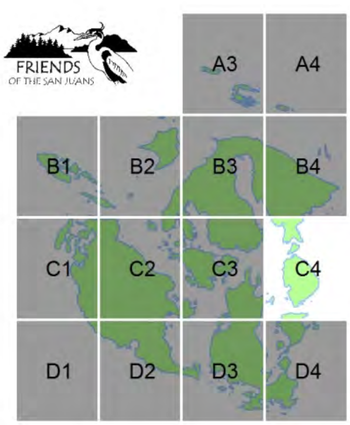
Drift Cells

Direction of Drift

Left to Right

Right to Left

FRIENDS OF THE SAN JUANS



C4

Forage Fish and Armor Process Impacts

1 0.5 0 1 Miles

N

LEGEND:

Documented Surf Smelt & Pacific Sand Lance Spawning Habitat

Impact to Sediment Supply-Armored Feeder Bluff

Impact to Sediment Transport-All Armor-Toe 4.5 ft. M.L.L.W.and Below

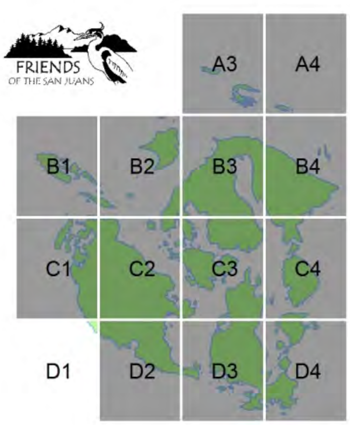
Drift Cells

Direction of Drift

Left to Right

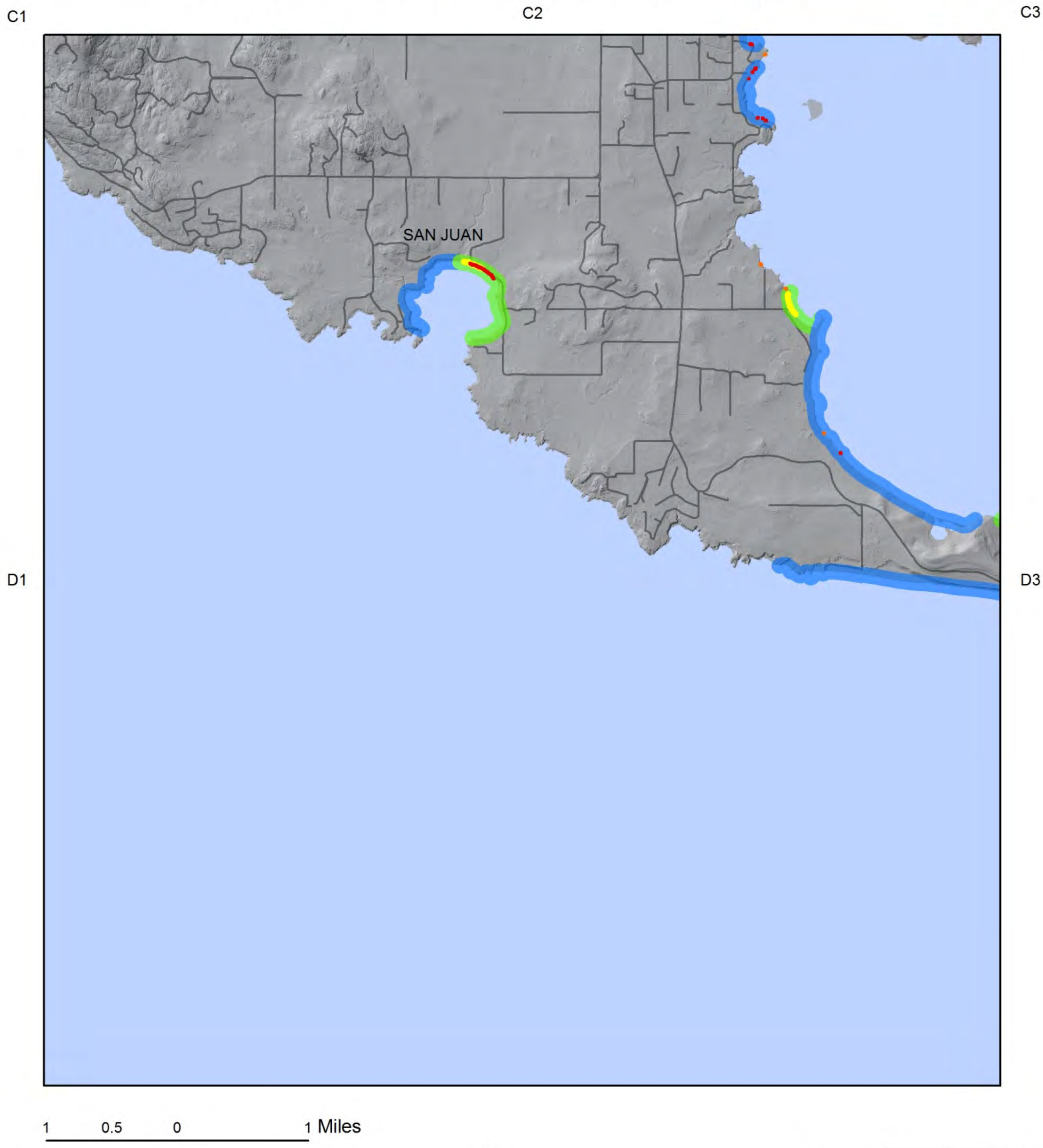
Right to Left

FRIENDS OF THE SAN JUANS



D1

Forage Fish and Armor Process Impacts



LEGEND:

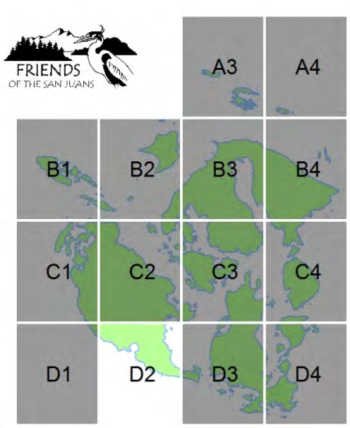
- Documented Surf Smelt & Pacific Sand Lance Spawning Habitat
- Impact to Sediment Supply-Armored Feeder Bluff
- Impact to Sediment Transport-All Armor-Toe 4.5 ft. M.L.L.W.and Below

Drift Cells

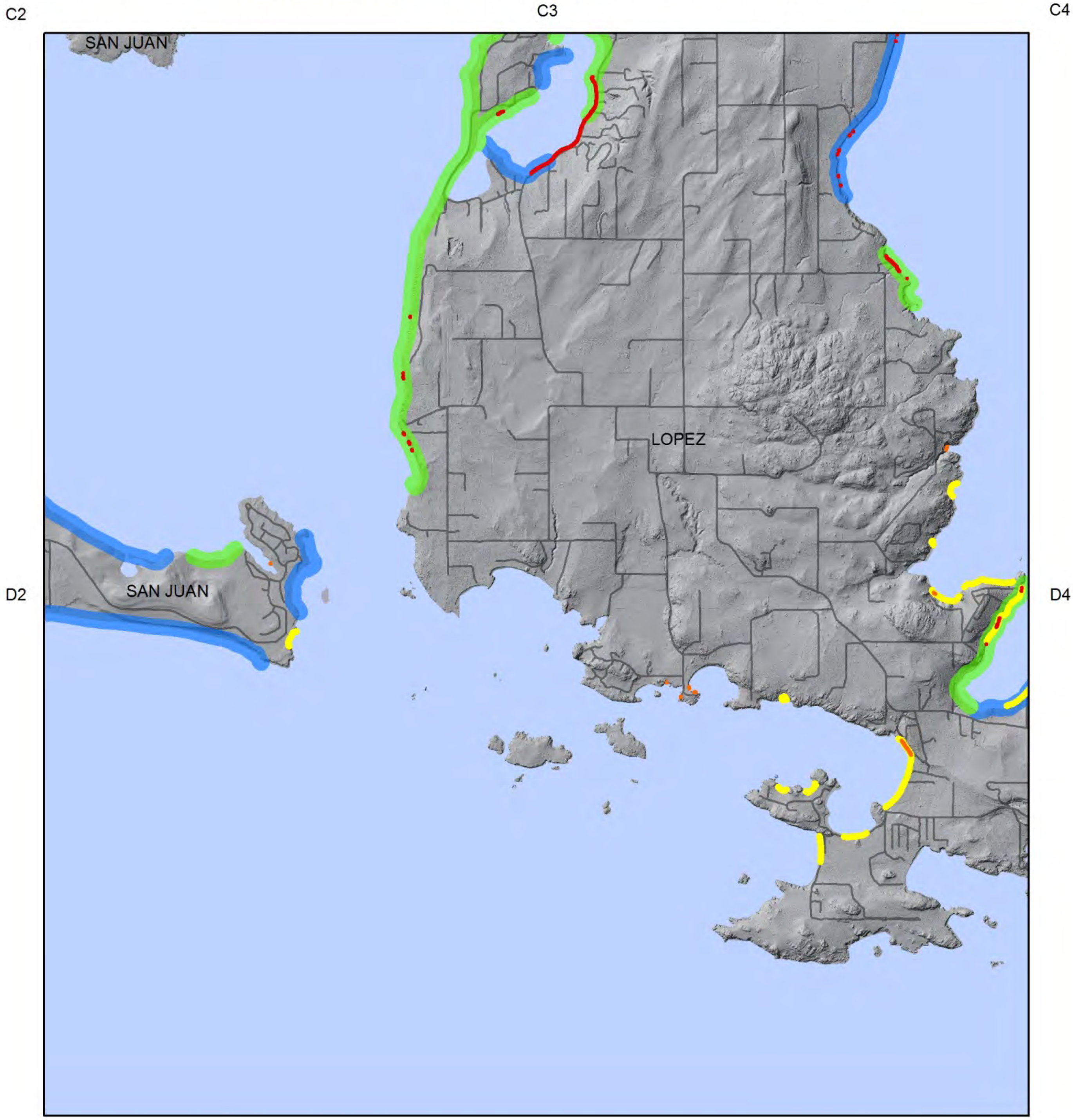
Direction of Drift

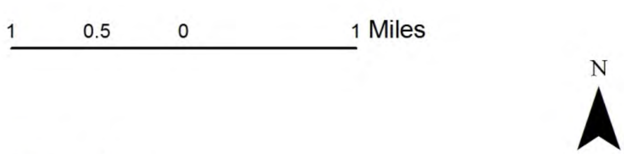
- Left to Right
- Right to Left

D2



Forage Fish and Armor Process Impacts





LEGEND:

Documented Surf Smelt & Pacific Sand Lance Spawning Habitat

Impact to Sediment Supply-Armored Feeder Bluff

Impact to Sediment Transport-All Armor-Toe 4.5 ft. M.L.L.W.and Below

Drift Cells

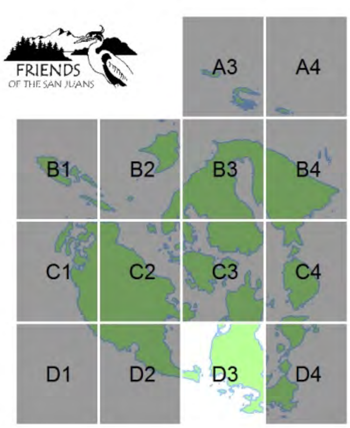
Direction of Drift

Left to Right

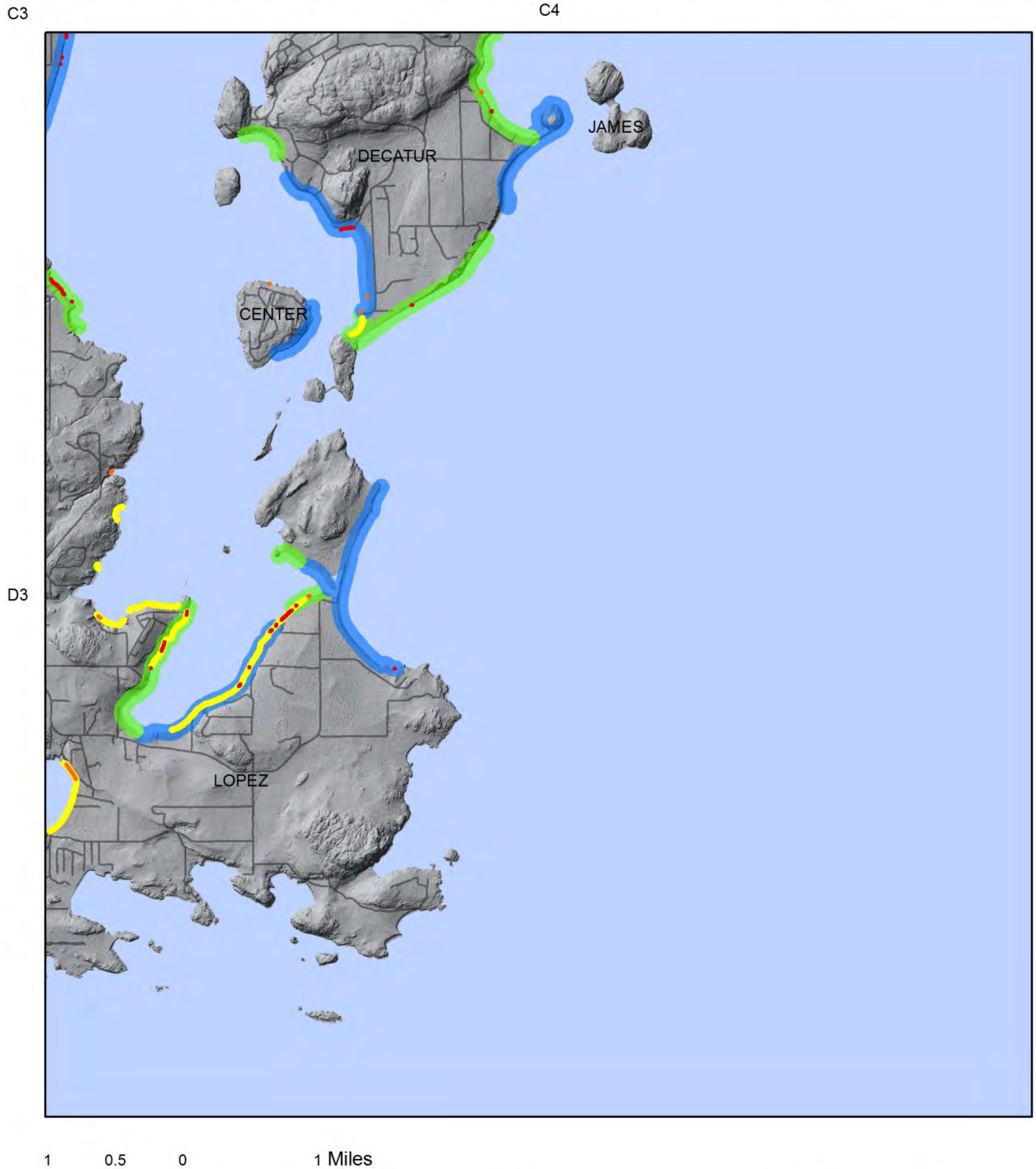
Right to Left

D3

FRIENDS OF THE SAN JUANS



Forage Fish and Armor Process Impacts



LEGEND:

Documented Surf Smelt & Pacific Sand Lance Spawning Habitat

Impact to Sediment Supply-Armored Feeder Bluff

Impact to Sediment Transport-All Armor-Toe 4.5 ft. M.L.L.W.and Below

Drift Cells

Direction of Drift

Left to Right

Right to Left

D4

FRIENDS OF THE SAN JUANS