Characterization of benthic habitat on Georges Bank

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Introduction

The Geological Survey of Canada Atlantic (GSCA) and the US Geological Survey (USGS) have, over the past five years, developed seabed habitat mapping programs in the Gulf of Maine. Originally, these two sister organizations worked independently in the Gulf, but cooperative research and mapping projects are now being developed (Todd et al., 2000; Todd et al., 2001). The shallow banks and deep basins of this region are important spawning areas of, and provide habitat for, commercial fish and shellfish species. Mapping sea floor habitat is the fundamental step necessary for scientific fisheries management, for monitoring environmental change and for assessing the impact of anthropogenic disturbance such as fishing and seabed engineering on benthic organisms. Also, mapping is the vital underpinning for the delineation of Marine Protected Areas.

The variety of approaches to benthic habitat mapping follows closely the number of researchers involved in studies of the sea floor. Thus for some a habitat map would be a bathymetric chart, for others a map of surficial sediments, and yet for others a map of an area occupied by a certain species. The strict definition of habitat is “a place where an organism lives”. All places in the ocean are inhabited by living organisms, therefore we are interested in distinguishing places that are somehow different and the differences are meaningful. Therefore our definition of habitat, as stated in Kostylev et al. (2002), is as follows: ”a spatially defined area where the physical, chemical and biological environment is distinctly different from the surrounding environment”. Note that this is a working definition of habitat that is suitable and specially formulated for the purpose of presenting the distribution of different habitat types on one map.

Sea floor shape and geological setting are almost always the leading factors in determining habitat type and quite often when talking about habitats one imagines an architecturally distinct place, such as a rocky shore or a tidal marsh. In our definition of habitats, we seek to distinguish distinct areas which share a number of common characteristics, not just the architecture of the contained space, but the whole ensemble of chemical physical and biological characteristics related to a given area (e.g. Valentine et al., this volume). It is often difficult to avoid subjectivity in defining borders of such areas, even when operating with one continuous factor (e.g. water depth). In the case of multiple factors, the task becomes increasingly difficult and it would be fair to assume, that the results are increasingly erroneous. Classification and mapping are clearly related and interdependent. While classification does not necessarily require visual representation, a map is visual by definition, and while imprecision in classification systems is hidden behind the terms, maps are assumed to correctly represent nature and the user will immediately discover discrepancies in practice if the map is wrong. Definition of classification boundaries is easy when it is used orally. However, when habitats are mapped for the purpose of ocean management or for understanding benthic ecosystems, imprecision in definitions of borderline values is amplified by spatial uncertainty. Additionally, it is easier to understand and interpret interactions of a few factors defining habitats, rather then a large number of them.

Habitat defined

Habitat is an organism-centric term. Habitats are ultimately defined by presence of benthic organisms. It is also clear that the assemblages of species, rather than individual species should be considered because distributions of groups of organisms best reflect the distribution of physical factors. We analyzed relationships of benthic assemblages and selected physical variables on Browns Bank (Kostylev et al., 2002; Kostylev et al., in press), and in the Sable Island Gully (Kostylev, 2001). Both studies showed that an interaction of several factors has the strongest effect on the distribution of communities. Typically, substrate type and water depth serve as a proxies for a number of co-varying physical factors. The explanation of this relationship is based on an ecological interpretation of interactions of organisms and environment, and is focused on the current state of benthic assemblages, regardless of history of succession, colonization and anthropogenic disturbance.

We propose an approach to habitat mapping that is based on the evolutionary perspective, namely on selective forces which have shaped the existing communities of benthic species and which have defined life history traits of species we find in different habitats. The evolutionary perspective on habitat was strongly encouraged by Southwood (1988), who promoted the idea of a ‘habitat template’, a classification based on defining habitats in terms of two main characteristics – adversity and stability of the environment. The disturbance axis reflects the intensity of habitat destruction or alteration, or durational stability of habitat in general. Adversity is related to the severity or unfavorableness of the habitat and factors that pose a cost for the physiological functioning of organisms. In the evolutionary perspective, an adverse environment will select species for their tolerance to extremes of physical factors. A disturbed environment will favor short-lived species which can quickly colonize an area and live offspring. The habitat template approach appears both theoretically valid and economical in terms of mapping and it avoids difficulties inherent in the interpretation of a large number of environmental variables.

This theoretical approach, together with the use of high-resolution acoustic mapping and optical sampling is applied to the characterization of benthic habitats on Canadian part of Georges Bank.

Study area

Georges Bank, (Fig. 1) like all the banks of the Gulf of Maine, was subject to the Wisconsinan glaciation. In contrast to other banks in the Gulf of Maine, evidence suggests that Georges Bank was not overridden by glacial ice (Todd et al., in prep). During this period, glaciers deposited a variety of sediment types on Georges Bank. Glacial ice occupied Northeast Channel to the north of the bank (Fig. 1) and outwash sediments were deposited on the bank as the ice melted. Following glaciation, a low stand of relative sea level occurred at about 14,000 years ago, subaerially exposing large areas of the continental shelf. The glacial sediments were eroded, winnowed and reworked by the subsequent sea-level transgression. The remnant sediment was reworked by wave and current action, building the complex pattern of present-day bedforms. The multibeam bathymetric image (Fig. 2) shows the Canadian portion of Georges Bank.

Two major types of surficial sediment have been identified on Georges Bank. Mobile sand dominates the shallowest part of the bank and gravel dominates the remainder of the bank. The sand comprises sheets and superimposed sand wave fields oriented perpendicular to the predominant semidiurnal tidal flow (Todd et al, in prep). The maximum measured sand wave height is 18 m and features of several meters high are ubiquitous. Much of the gravel on the Georges Bank scallop grounds is believed to have been disturbed by fishing activity.

Geophysical, geological and biological information:

Multibeam bathymetric data, including backscatter strength (Fig. 3), were collected in the Gulf of Maine using Simrad EM1000 and 1002 systems. The new generation of multibeam sounders consist of 60 to 250 beams which sweep across the seabed providing a wide swath of ensonification. A series of parallel survey tracks were used to ensure 100% sea floor coverage.

The Geological Survey of Canada and the US Geological Survey collected 166 sediment samples in the study area by grab, dredge and submersible and the samples were analyzed for grain size distribution. This information was used in conjunction with 116 photographic stations (1884 seafloor photographs) for interpretation of surficial sediment type. Sampling locations are shown on Fig 3.

Multibeam backscatter data were used to interpolate the distribution of sediment grain sizes on the bank. There is a significant log-linear relationship between backscatter values and grain size as estimated from groundtruthing samples (Fig. 4, A). Observations on the relative fraction of sand and gravel both in grab samples (Fig. 4, B) and estimated from underwater imagery (Fig. 4, C) corroborate this relationship and allow re-classification of the backscatter information into areas of sand, gravel and mixed sediment (Fig. 5). This preliminary map of sediment type will be superceded by geology map based on geophysical and geological groundtruth data (Todd et al., in prep).

Underwater photographs were analyzed for presence or absence of megabenthos (organisms generally larger then 1 cm) and organisms were identified to the best possible taxonomic level. Frequency of occurrence of different taxa was calculated for each station and used in further classification and statistical analyses. Continuous video recording with two cameras (oblique and vertical) from each station revealed larger mobile species (e.g. fish) and provided insight into morphology of the sea floor.

Oceanographic information

Water temperature, salinity and near bottom currents data were obtained from the Gulf of Maine circulation model developed by the Department of Fisheries and Oceans (C. Hannah, personal communication, 2002), and augmented by a database of oceanographic observations (Yashayaev 1998). The data were stored in MapInfo GIS and continuous coverage for the study area was produced by inverse distance weighting interpolation.

All data used in the analyses were gridded with Vertical Mapper to a resolution of 200 meters, which was optimal for the reduction of noise in the original data, and produced of a grid file of manageable size for the subsequent computations (Fig. 6).

Mapping of habitat disturbance

In this study we investigated the natural disturbance of seafloor sediments on the bank, based on the knowledge of grain size distribution and strengths of the mean tidal currents. Backscatter strength strongly correlates with the logarithm of mean grain size of surficial sediment, and the relationship was used to convert the backscatter map into the grain size map (Fig. 5). A simple difference between the major tidal current and critical current velocity needed to initiate movement of particles of given size served as a guide for defining areas where sediment is disturbed by tides only. Tidally disturbed areas correspond to the sedimentary bedforms observed on multibeam image (Fig. 2). The mean circulation current comprises about 10% of the major tidal currents, and was not taken into account. Storms and swells can initiate sediment mobility down to considerable depths, which is confirmed by our observations of sand waves in the deeper part (100m) of the bank. Because information on storms for the study area were not available, water depth was used as a proxy for the storm-related disturbance. A simplified approach to modeling disturbance was taken by standardizing the values of water depth, backscatter strength and current strength, and using them in an additive model. We reclassify the disturbance into high and low values by splitting the range at the median, based on frequencies of map cell values (Fig. 7). The red isoline on the stability map delimits the area with tide-related disturbance, the blue isoline separates the area characterized as disturbed from undisturbed. The tide – generated sediment mobility occurs well within the overall high disturbance area, which covers an area twice the size. Thus the sediment features observed in low disturbance area are possibly created by the low frequency events, such as large storms.

Mapping of habitat adversity.

Despite our need to know and analyze as many relevant variables as possible, we are always restricted in the availability and quality of high-resolution data related to a study site. For Georges Bank, water temperature, salinity and chlorophyll concentration (as defined by satellite imagery), were used as proxies for the adversity of habitats. Hargrave and Peer (1973) show that chlorophyll concentration is a useful indicator for benthic biomass. We estimated an average concentration of chlorophyll in the surface waters from composite SEAWIFS images (School of Marine Sciences, University of Maine, http://wavy.umeoce.maine.edu) and the reciprocal of the resulting variable was used as one of the indicators of habitat adversity. We also assumed that, for the benthic fauna of the outer shelf within this biogeographic zone, the lower average temperature, lower salinity and higher variability in water temperature would all contribute to the adversity of the environment. A composite variable (Fig. 8) was calculated as a maximum value of any of the standardized variables at a given location. Thus all of these were given equal weight, and any of them were allowed to be limiting for benthos. Note that this is different to the averaging approach chosen for the disturbance factors. Within the study area adverse and benign environments were defined by subdividing the 'adversity variable' by the median.

The two resulting grids were queried for 'adverse disturbed', 'adverse undisturbed', 'benign disturbed' and 'benign undisturbed' combinations of factors, and mapped. The resulting map (Fig. 9) shows these four classes of environment. This map is repeatable and testable.

Results

Analysis of frequencies of occurrence of benthic megafauna from optical sampling serves as a good indicator of habitat preference. Stations were classified using the Bray-Curtis similarity coefficient. The resulting distribution of different clusters (Fig.

9) corresponds well to the habitat template. Stations from same clusters show strong fidelity to a single habitat type (Pearson Chi-Square = 97.196, df = 27, p <0.0001). For example, stations of the disturbed adverse part of the bank (blue area) are grouped in one cluster (brown circles). Stations of disturbed benign area (yellow) are represented by two clusters: stations with typical hard substrate fauna (blue circles) and sand dwelling fauna (light blue circles). There is much weaker relationship between the clustering of grab samples and the habitat template. Generally we assume that the disagreement in matching the habitat template in the clustering of stations based on grabs (points) is based on the nature of grab sampling, which is localized, while the optical sampling (transects) characterizes larger extents of the sea floor.

Conclusions

Habitat template is a novel concept for summarizing habitat properties, which are relevant to benthic organisms. It includes evolutionary and ecological considerations in spatial mapping of habitat types, and allows the number of variables required for interpretations of observed patterns to be minimized. It is possible that sediment type may be nested once again within the habitat template. For example, benign undisturbed areas, such as gravel habitats on the northern edge of the bank, and stable sands in the south of the bank have faunas which should carry similar life history traits, but which are composed of a different sets of species. The clear quantitative definition of adversity and disturbance has not been agreed upon yet (Southwood, 1988) and construction of the adversity axis may require additional theoretical work. The accuracy and precision of this classification are as good as the data used, and while the data on bathymetry and sediments are of high resolution, oceanographic variables are either interpolations or results of modeling. However the model can be applied locally in order to discover general environmental trends and understand the differences between habitats and benthos of different areas. Optical sampling has proven to be better for definition of the habitat- animal relationship and is a quick and cost-effective method of habitat surveying compared to grab sampling. High-resolution seafloor mapping aided by interdisciplinary information on the water column, and enforced by sound ecological theory greatly improves our understanding of the ecology of benthic habitats.

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Figure captions:

1 Location map of the study area. Canadian section of eastern Georges Bank is shown in red.

2 Multibeam sonar bathymetry of Georges Bank. Depths are color coded from red (40m) to dark blue (200m)

3 Multibeam sonar backscatter strength of Georges Bank with locations of sampling stations. Dark (strong) backscatter areas signify coarser-grained substrates then light-toned areas.

4 Relationship between sediment grain size and backscatter brightness. A) Mean grain size from grab samples and archive data; B) Percent sand/gravel from archive data; C) Percent surface cover of sediment types from image analysis

5 Reclassified backscatter map based on the relationship of gain size and backscatter.

6 Oceanographic variables used in the habitat classification. 1) backscatter; 2) – Major tidal component (m/sec); 3) – Average bottom water temperature (^{o}C); 4) Bottom water salinity (ppm); 5) Variability in water temperature (^{o}C); 6) Chlorophyll concentration (mg/m^3)

7 Stability component of habitat template. The red isoline on this map delimits the area with tide-related disturbance, the blue isoline separates the area characterized as disturbed from undisturbed

8 Adversity component of the habitat template. Red is high adversity and blue is low.

9 Habitat template mapped onto study area. Blue is adverse and disturbed, yellow is benign and disturbed, brown is benign and stable, green is adverse and stable. Clustering of stations based on the Bray Curtis similarity of fauna is shown with circles of different color, based on optical data only.

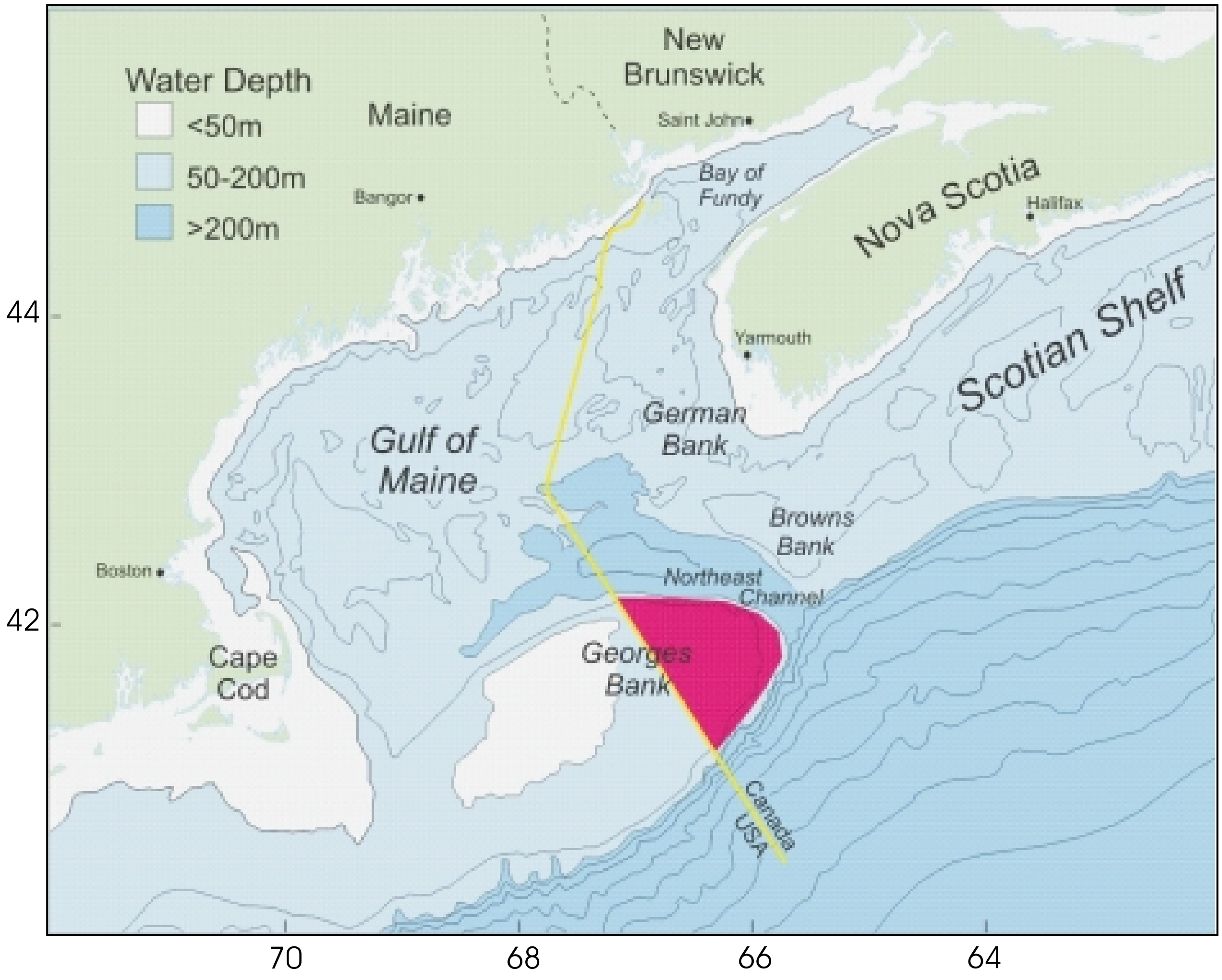
Water Depth
<50m
50-200m
>200m
Maine
New Brunswick
Saint John
Bangor
Bay of Fundy
Nova Scotia
Halifax
Scotian Shelf
Yarmouth
German Bank
Gulf of Maine
Browns Bank
Northeast Channel
Boston
Cape Cod
Georges Bank
Canada
USA
44
42
70
68
66
64

Fig. 1.

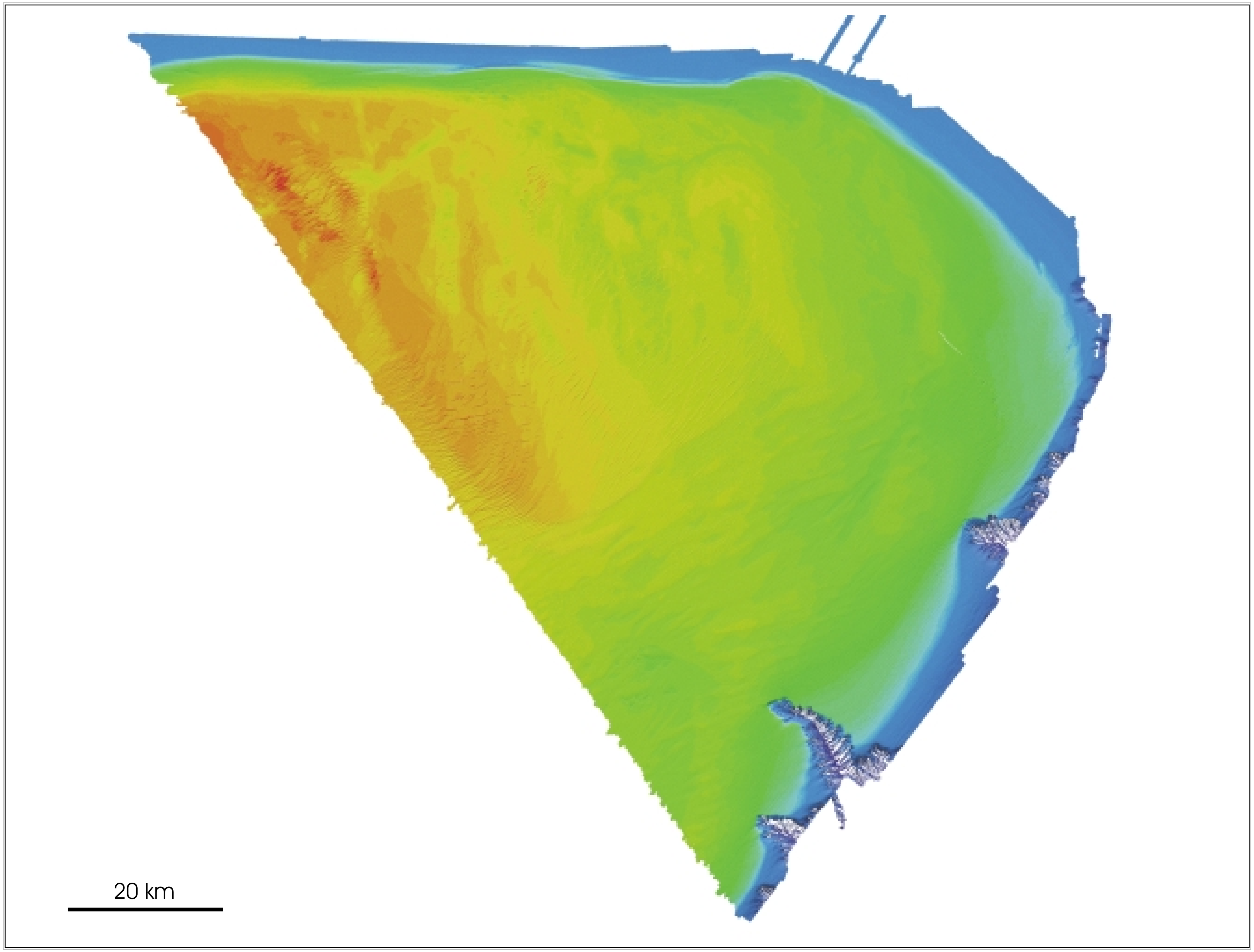

Fig. 2.

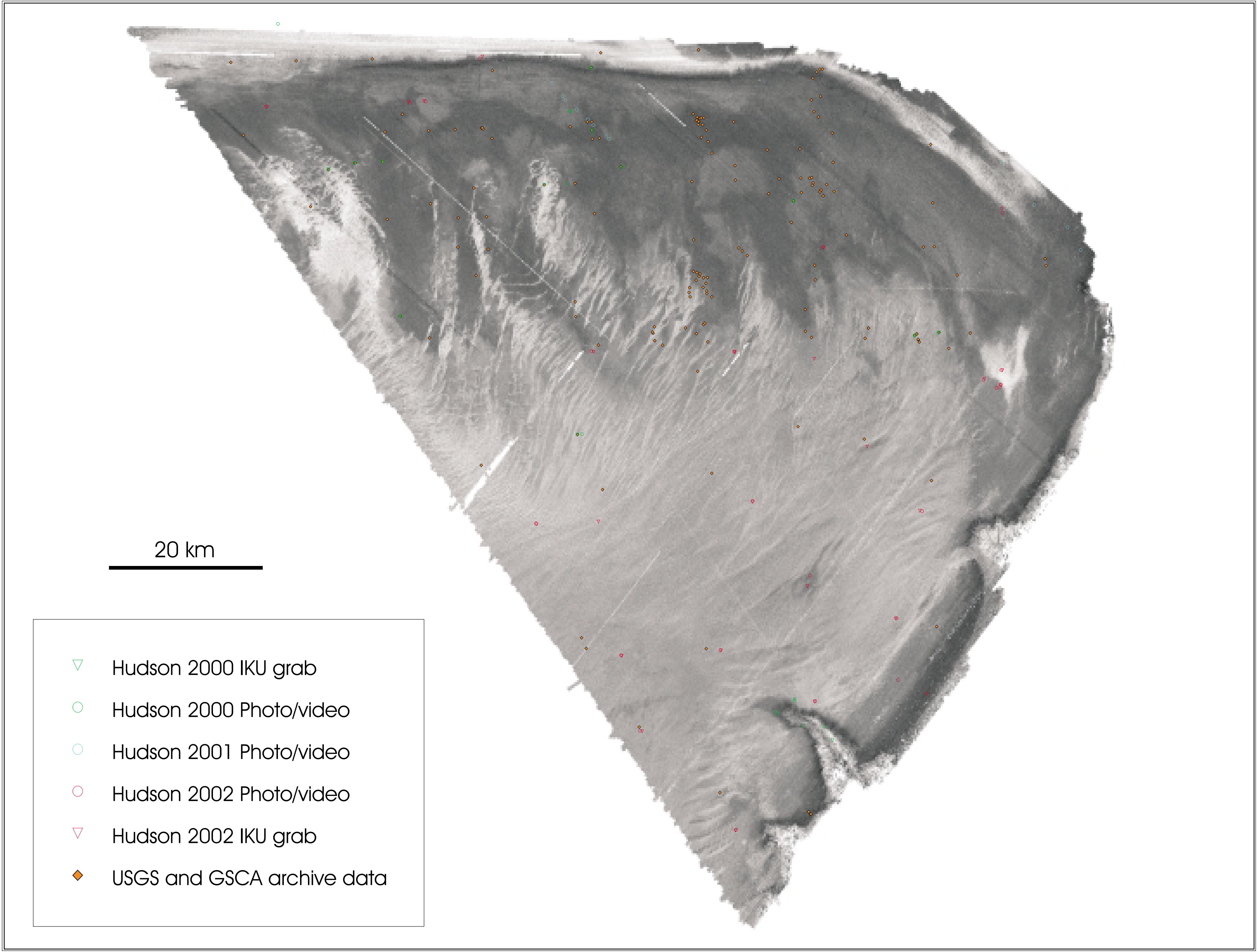
20 km
▽ Hudson 2000 IKU grab
○ Hudson 2000 Photo/video
○ Hudson 2001 Photo/video
○ Hudson 2002 Photo/video
▽ Hudson 2002 IKU grab
◆ USGS and GSCA archive data

Fig. 3.

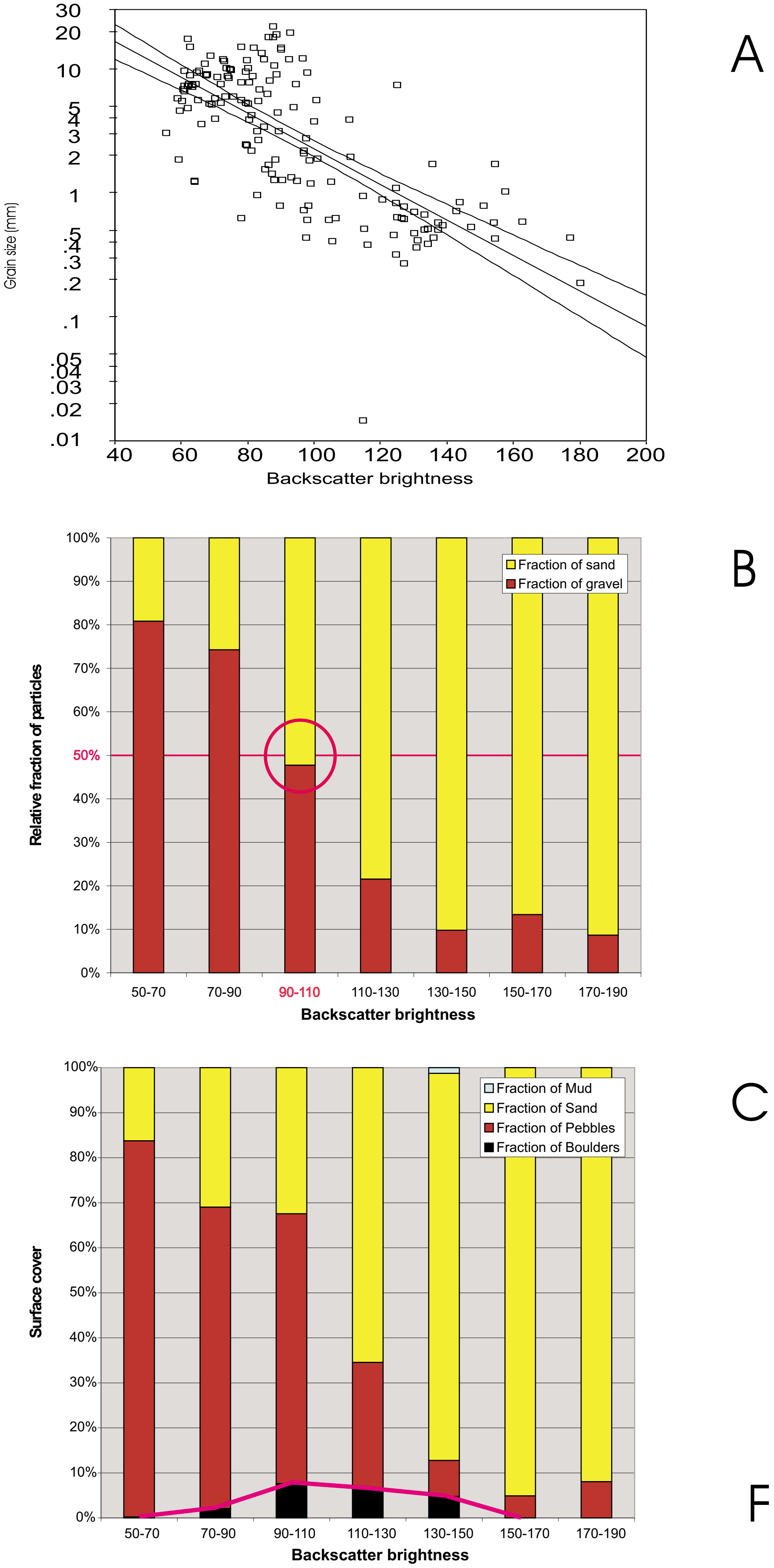
A
Grain size (mm)
30
20
10
5
4
3
2
1
.5
.4
.3
.2
.1
.05
.04
.03
.02
.01
40
60
80
100
120
140
160
180
200
Backscatter brightness
B
Relative fraction of particles
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Fraction of sand
Fraction of gravel
50-70
70-90
90-110
110-130
130-150
150-170
170-190
Backscatter brightness
C
Surface cover
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Fraction of Mud
Fraction of Sand
Fraction of Pebbles
Fraction of Boulders
50-70
70-90
90-110
110-130
130-150
150-170
170-190
Backscatter brightness

Fig. 4.

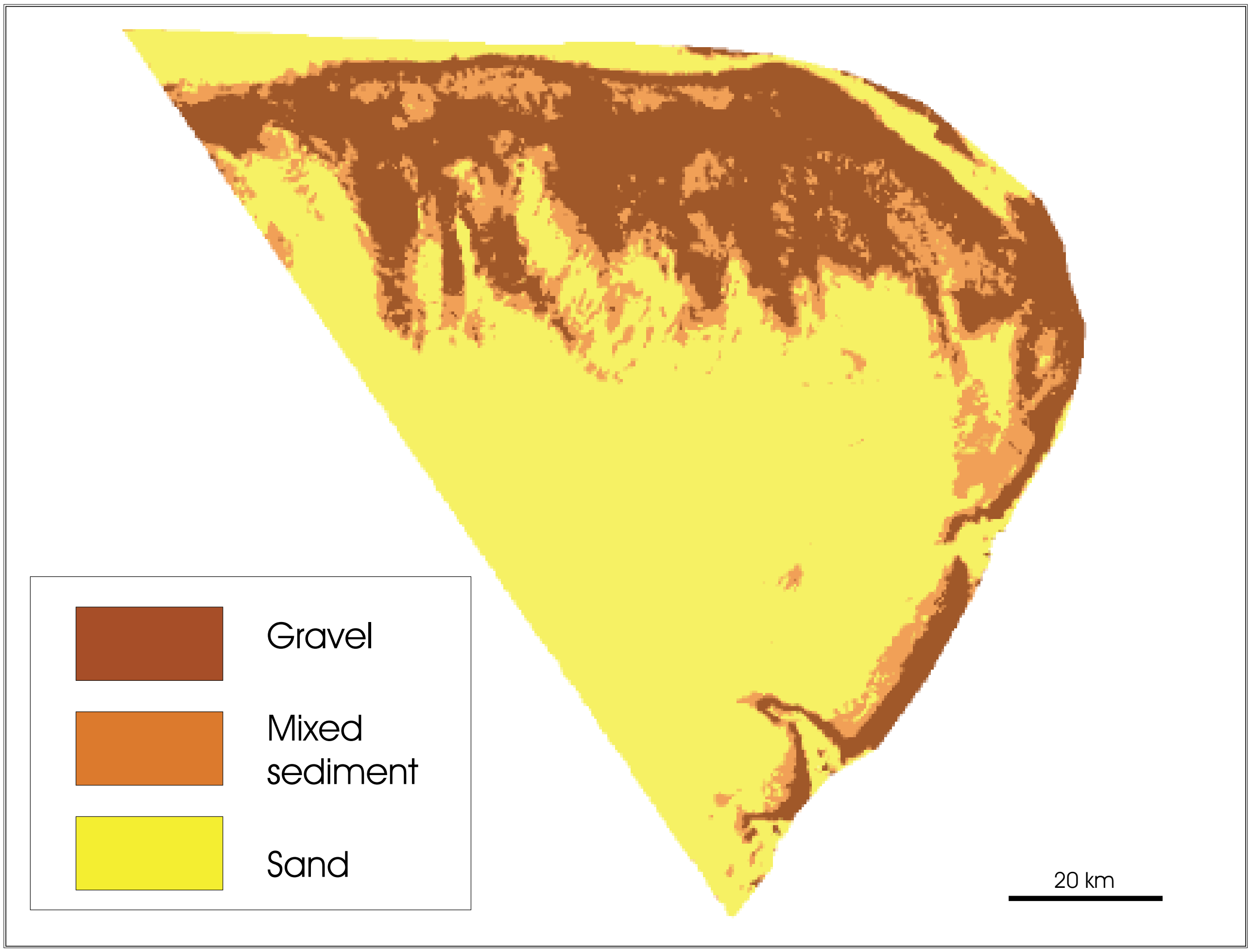

Fig. 5.

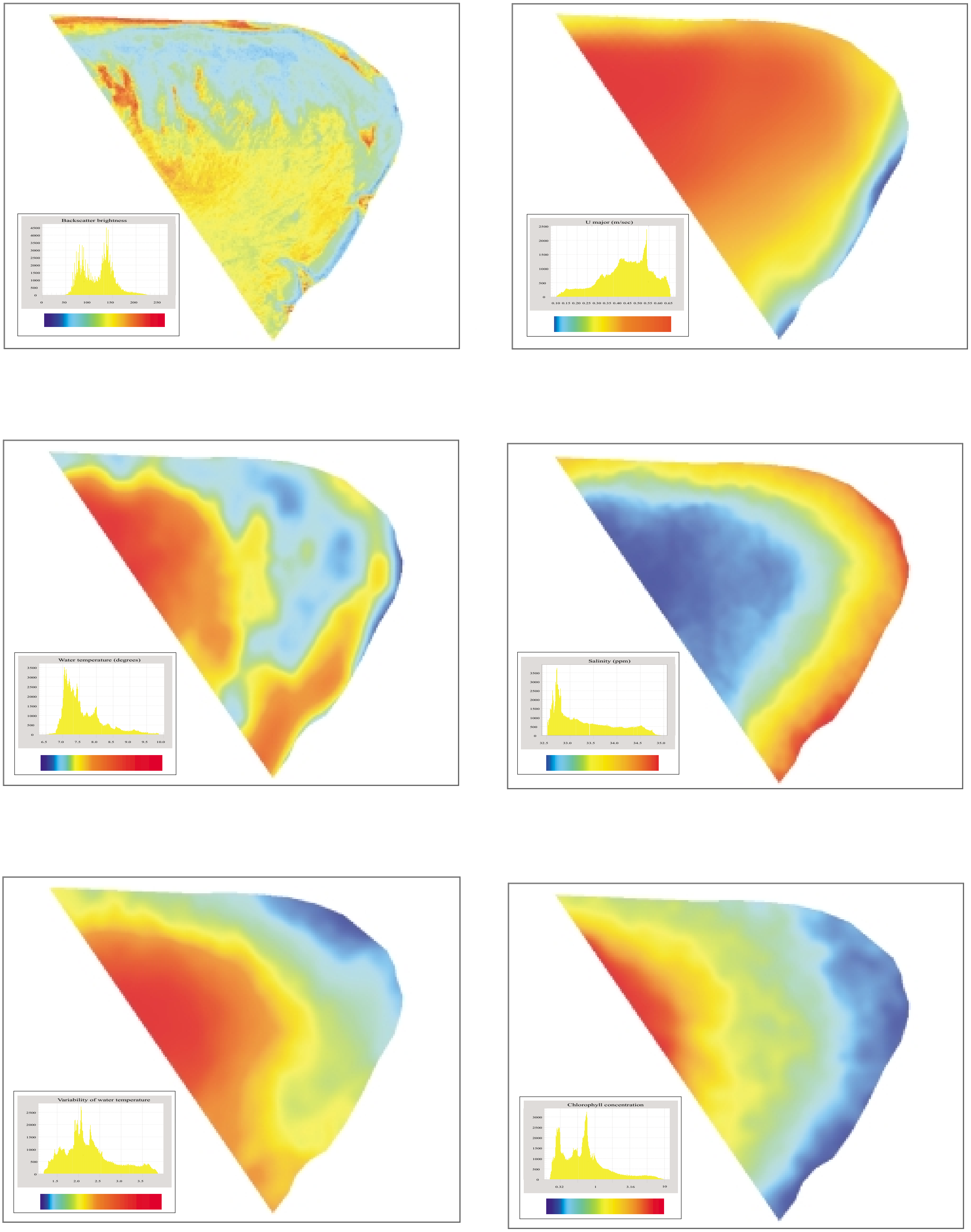
Backscatter brightness
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
50
100
150
200
250
U major (m/sec)
2500
2000
1500
1000
500
0
0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65
Water temperature (degrees)
3500
3000
2500
2000
1500
1000
500
0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
Salinity (ppm)
3500
3000
2500
2000
1500
1000
500
0
32.5
33.0
33.5
34.0
34.5
35.0
Variability of water temperature
2500
2000
1500
1000
500
0
1.5
2.0
2.5
3.0
3.5
Chlorophyll concentration
3000
2500
2000
1500
1000
500
0
0.32
1
3.16
10

Fig. 6.

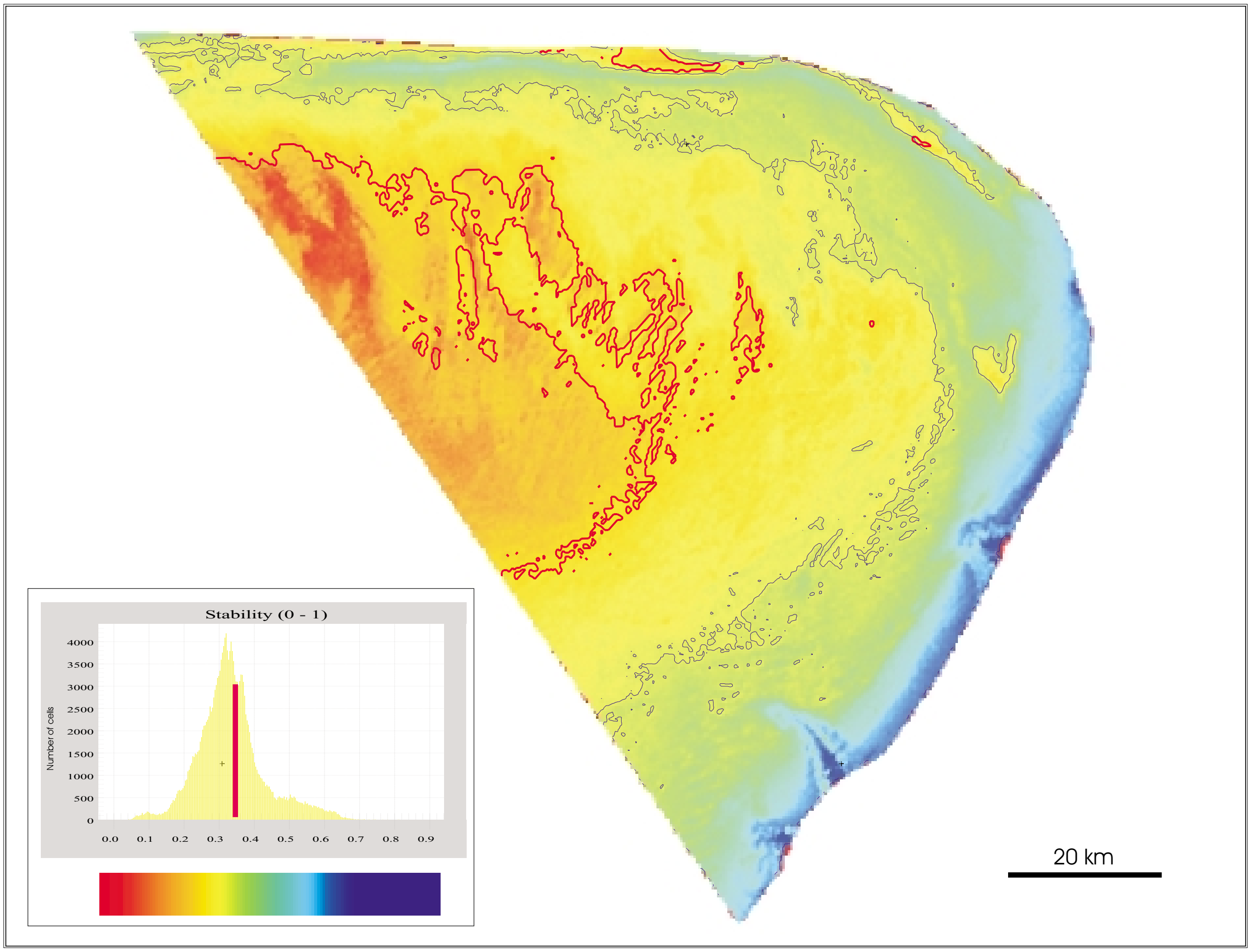
Stability (0 - 1)
4000
3500
3000
2500
2000
1500
1000
500
0
Number of cells
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
20 km

Fig. 7.

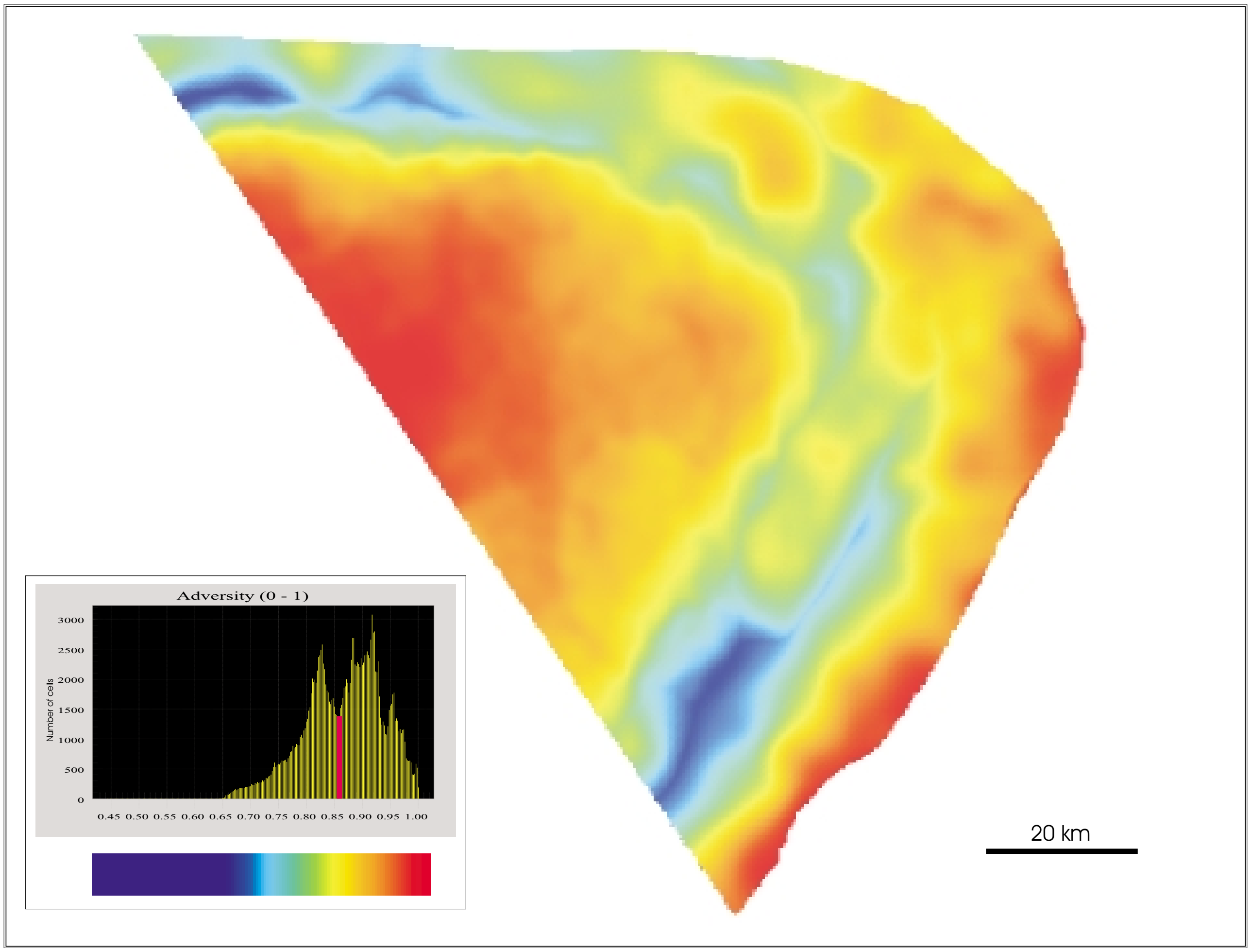
Adversity (0 - 1)
Number of cells
3000
2500
2000
1500
1000
500
0
0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80 0.85 0.90 0.95 1.00
20 km

Fig. 8.

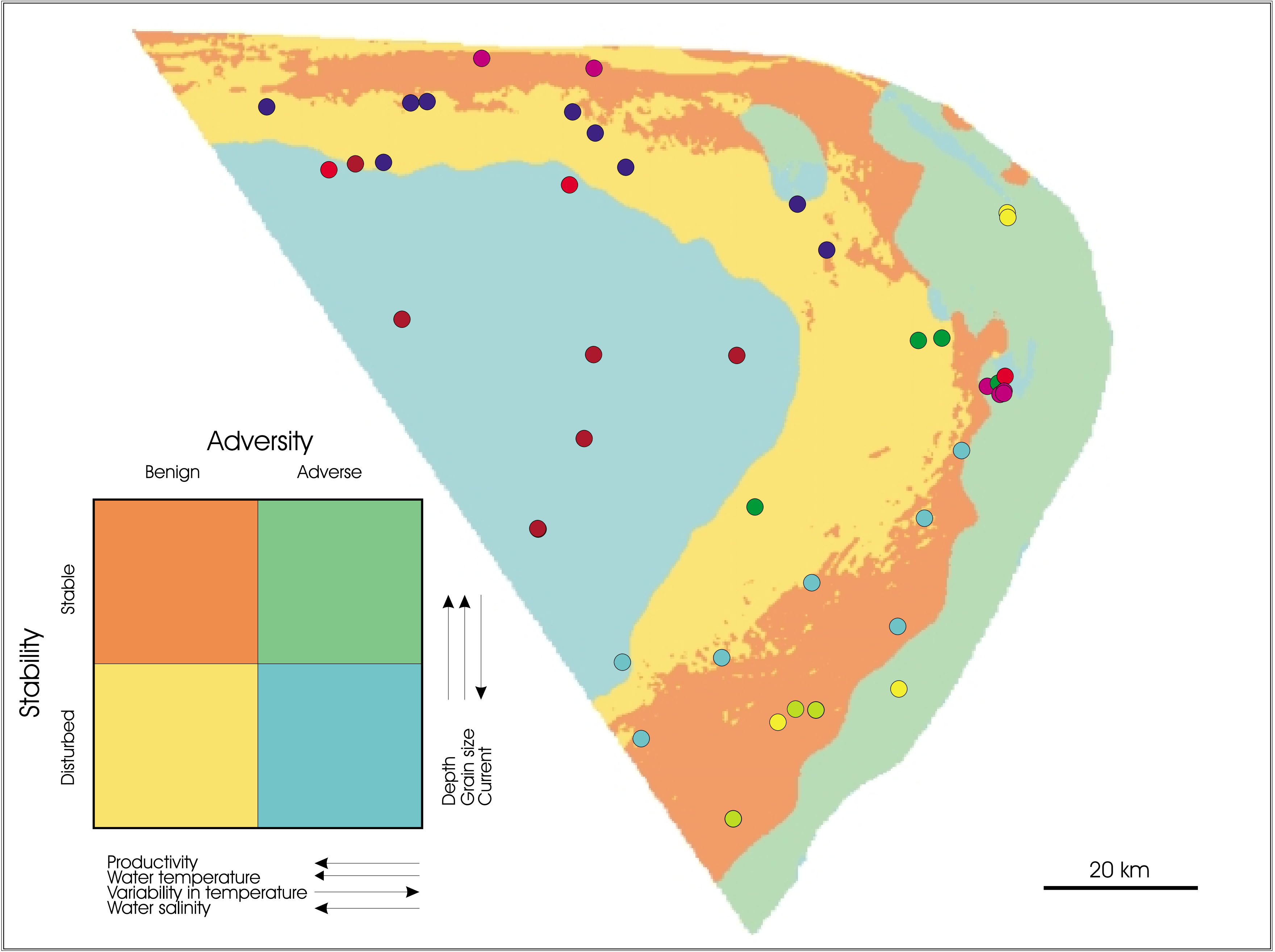
Adversity
Benign
Adverse
Stability
Stable
Disturbed
Depth
Grain size
Current
Productivity
Water temperature
Variability in temperature
Water salinity
20 km

Fig. 9.