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**CONSIDERATIONS FOR USING REMOTE SENSING TECHNOLOGIES TO ASSESS  
INJURY TO BENTHIC HABITATS FROM VESSEL GROUNDINGS**

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# CONSIDERATIONS FOR USING REMOTE SENSING TECHNOLOGIES TO ASSESS INJURY TO BENTHIC HABITATS FROM VESSEL GROUNDINGS

## Introduction

Vessel groundings in seagrass and coral habitats can cause significant injury to these benthic communities. Injury assessment requires information on the areal extent and degrees of injury at the grounding site, including the inbound and exit vessel tracks. Remote sensing technologies are often proposed as a data-collection method. This document provides a summary of the types of remote sensing technologies that might be appropriate to use following vessel grounds, their characteristics, costs, ordering information, and guidelines for use.

Conceptually any object that gathers information without touching the target can be considered a remote sensor (the human eye being the classic example). This guide will focus on commercially available satellite-based sensors operating in the visible and near visible range of the electromagnetic spectrum. Table 1 shows important terminology for describing satellite sensors. Table 2 shows current commercial satellite sensors and their spatial resolutions. Figure 1 compares spatial resolutions in imagery.

**Table 1.** Terminology for describing satellite sensors.

<b>Term</b>	<b>Description</b>	<b>Comments</b>	<b>Considerations</b>
Spatial resolution	The size of an individual pixel in a recorded image.	No object smaller than the spatial resolution will be identifiable in the image; an object needs to be represented by at least 4 pixels to be recognized in visual interpretation.	Primary factor for damage assessment. Want resolution no greater than 30m and ideally less than 1m.
Multispectral (multi)	The sensor records data in multiple bands of the electromagnetic spectrum.	High spatial resolution satellite sensors typically record multispectral data in 4 bands: Blue, Green, Red, and Near Infrared. These bands can be analyzed individually or combined.	Blue, Green, and Red bands allow for natural color images. The Blue band penetrates water better. Infrared is primarily used for vegetation.
Panchromatic (pan)	The sensor records a single wide band of data allowing for a higher spatial resolution.	High spatial resolution satellite sensors typically collect a pan band in addition to their multispectral bands.	Pan is generally displayed in greyscale. Pan can be merged with multispectral imagery (see Table 3).
Revisit time	How often the satellite can take images of an area.	Many satellites can rotate their sensors to image areas with increased frequency. However, an image at a great angle from vertical can be hard to interpret.	A high revisit time increases the chances of getting timely information. Generally, revisit time is expressed in terms of getting near vertical imagery.
Swath width	The width of the image.	Width and length determine the area covered by the image. Length is a continuous path as the satellite moves above the surface of the earth.	For most incidents the swath width is not a concern. It is possible that an event might need to be covered by multiple swaths, thus increasing costs.

**Table 2.** Characteristics of current commercial satellite sensors from highest to lowest spatial resolution. The “Order” column can be used to look up order information in Table 4.

Satellite/Sensor	Multi Spatial Resolution	Pan Spatial Resolution	Revisit	Swath	Order
GeoEye-1 <sup>+</sup>	1.64m	0.41m	~ 3 days	15.2km	GeoEye
Quickbird	2.4m	0.60m	3 - 7 days	16.5km	DigitalGlobe
IKONOS	3.2m	0.82m	~ 3 days	11.3km	GeoEye
OrbView-3	4m	1m	~ 3 days	8km	GeoEye
KOMPSAT-2	4m	1m	~ 3 days	15km	SPOT
IRS RS-1*	5.8m	N/A	5 days	23.9km	GeoEye
FORMOSAT-2	8m	2m	Daily	24km	SPOT
SPOT 5*	10m	5m	3 - 5 days	60km	SPOT
SPOT 1-4*	20m	10m	3 - 5 days	60km	SPOT
IRS 1C/1D/RS-1*	23.5m	5.8m	24 days	141km	GeoEye
Landsat 7*	30m	15m	16 days	170km	Landsat
Landsat 4-5*	30m	N/A	16 days	170km	Landsat
<b>Compare to Aerial Photography</b>	cm to m (determined by flight altitude)	cm to m (determined by flight altitude)	Daily or as desired	100s of m (determined by flight altitude)	

<sup>+</sup> GeoEye-1 is scheduled to be launched in early 2007.

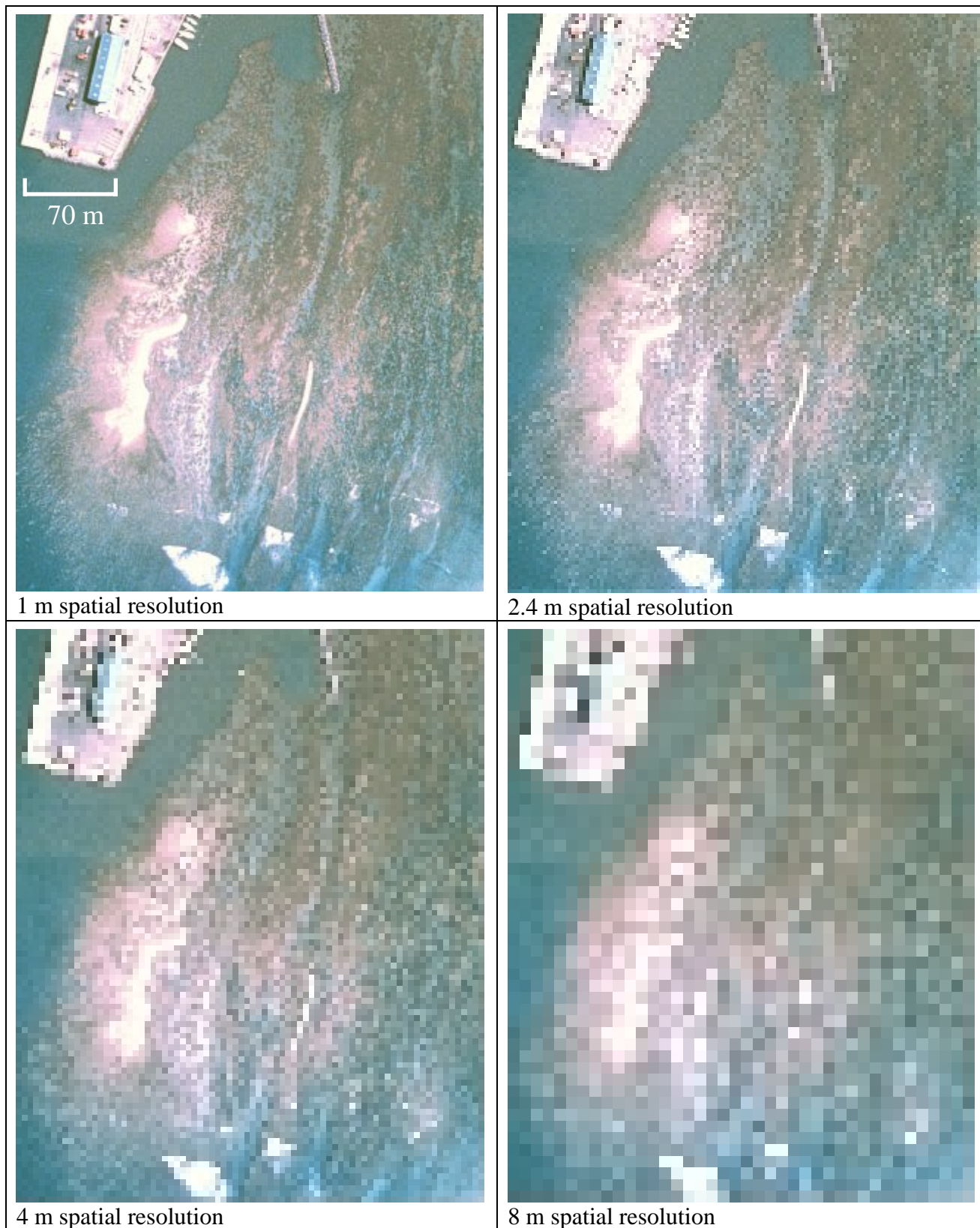
\* These platforms carry additional low spatial resolution sensors not discussed here.

## Costs and Ordering

Traditionally imagery was sold in square sections based on the swath width called scenes. For example a SPOT scene would be 60x60 kilometers, and if your study area fell on two scenes you would pay full price for both. Recently companies have begun selling image scenes based on a user defined area of interest (AOI). Pricing for an AOI is based on area and the AOI can be irregular and made up of multiple satellite passes (and thus multiple images). The small area of vessel impacts will probably always bump into the minimum order costs for an AOI.

Minimum order costs for a new high resolution multispectral scene with basic geometric correction are around \$2,500. However, additional costs for better geometric processing, the pan band, and pan merge product (see Table 3) can quickly raise this cost to around \$4,500 for a scene. Priority collection can add an additional \$2,200 (for a worst case total of ~ \$6,700 for a study area). Base costs and processing costs for 10 to 20 meter (m) imagery can drop to \$2,000 or less and processed 30m Landsat imagery is available for \$600 dollars a scene. Archived imagery can be 50% off the base price. Pricing is fairly competitive and you might be able to get imagery for less than these estimated costs. Bulk discounts and repeat visit discounts are often available.

Imagery can be purchased by calling the company directly or by using an imagery re-seller. Some companies have sales representatives specifically for government customers. Authorized re-sellers can be found on the company’s web site. They generally charge a



**Figure 1.** A single image at varied spatial resolutions. Appropriate spatial resolution will vary depending on the size of the grounded vessel and impact area.

**Table 3.** Terminology when ordering satellite imagery.

<b>Term</b>	<b>Description</b>	<b>Considerations</b>
New collect	New imagery that the satellite will be tasked to collect.	New collection can occur the next time that the satellite passes the vessel location. Worse-case scenario is that the satellite has just passed the location and the user must wait the full revisit time.
Collection priority	When two customers task data that needs to be collected at exactly the same position of the satellite (but cover different areas) the conflicts is resolved by assigning priority to certain customers.	In non-national emergency situations this is usually not a problem as there area rarely two orders that need the satellite at exactly the same time. You can pay extra to have a higher priority.
AOI (Area of Interest)	The AOI defines the area for which imagery is to be collected.	An AOI can be defined by a simple Lat/Long point or by a complex bounding box in a GIS format (e.g. shapefile)
Processing Level	The satellite imagery can be purchased in a raw form or with various radiometric and geometric corrections performed by the vendor.	Generally you want the highest processing level you can afford. This can add time to the order but makes the imagery easier to use with other GIS data.
Turnaround time	The time after imagery collection that the vendor needs to process the imagery and ship it to you. This is affected by your collection priority and processing level.	At best this is 1 to 3 business days. Adding the revisit time for imagery collection, and your best total time needed for an order is between 2 and 6 business days.
Pan merge or Pan sharpening	A product which combines multi and pan data from a sensor to produce a higher spatial resolution natural color image.	Can take longer for the vendor to deliver or the user needs software to merge the products themselves. Can complicate image processing techniques. Can aid in visual interpretation.
Archived imagery	Imagery that has previously been collected and is generally readily available to purchase.	Archived imagery can be useful for accessing pre-grounding conditions, is much less expensive, and can often be viewed and ordered through the vendor's website.

percentage fee on top of the purchase, but have advantages. Look for a re-seller who offers imagery from multiple vendor companies and can easily compare current prices. A good re-seller should have contacts with the vendors that would allow for off-business hour imagery purchases. A re-seller should have the software and technicians to provide additional image processing and analysis if desired (e.g. the re-seller might be able to produce a pan merge product more quickly and cheaply than the vendor). An established relationship with a sales representative or re-seller who understands your imagery needs would be very beneficial for timely image ordering, acquisition, and pricing. Table 3 includes important terminology for ordering imagery. Table 4 provides contact information for direct ordering from the satellite companies.

**Table 4.** U.S. order information for satellites mentioned above as of the date of this publication.

<b>Company</b>	<b>Web Site</b>	<b>Phone</b>	<b>Hours</b>
Digital Globe	<a href="http://www.digitalglobe.com">http://www.digitalglobe.com</a>	1-800-496-1225	Sun – 1 pm to 10 pm MST M-T – 5 am to 10 pm MST Fri – 5 am to 6 pm MST
GeoEye	<a href="http://www.geoeye.com">http://www.geoeye.com</a>	1-800-232-9037	M-F, 8 am - 5:30 pm EST
SPOT	<a href="http://www.spot.com">http://www.spot.com</a>	1-703-715-3100	M-F Business hours EST
Landsat	<a href="http://edcsns17.cr.usgs.gov/Eart&lt;br/&gt;hExplorer/">http://edcsns17.cr.usgs.gov/Eart hExplorer/</a>	1-800-252-4547	M-F, 8 am. to 4 pm CST

### When to Purchase Imagery

The responder needs to determine if purchasing satellite imagery will provide useful cost-effective information for a particular grounding. Table 5 lists factors at the field site that can affect the decision to purchase satellite imagery. Time and costs will increase as the responder integrates the imagery with other GIS data, categorizes features in the imagery, and tries to quantify injury. Acquisition of ancillary data sets presented in Table 6 can allow for easier and more in-depth satellite imagery interpretation. Finally, costs for computers, imagery compatible software, processing time, and storage of large image files should be considered. These costs can vary depending on the level of image interpretation and analysis desired.

**Table 5.** Factors affecting the decision to purchase imagery.

<b>Factor</b>	<b>Description</b>
Purpose of imagery	Imagery can aid in planning, visualization, and quantification of the impacted area. In remote areas, imagery can be used for a preliminary assessment of the scale of injury. In conjunction with field data, imagery can be used to classify habitat types, injury types, and degree of injury.
Area of damaged habitat	The size of the impacted area should be large enough to warrant the purchase (minimum damaged area should be ~100m <sup>2</sup> ). Larger areas will be more easily identified in the imagery and may allow delineation of different types of damage.
Water clarity/depth	In very clear water, imagery should be useful to a depth of about 30m. Deeper, turbid, or murky water may limit the usefulness of satellite data.
Substrate type	Generally imagery would be used for seagrass, coral, and/or hardbottom and not used for sand/mud.
Cloud cover/ sun glint	Areas with lots of cloud cover may be hard to acquire timely imagery. Satellite imagery will not be able to control for cloud cover or sun glint.
Tide	Satellite imagery will not be able to control for tide levels.

**Table 6.** Ancillary data for imagery interpretation and processing.

Data	Description
	Oblique photos can be used to note visual differences in impact areas that can be looked for in the imagery. Combine with GPS and GPS PhotoLink for easier use in GIS systems.
Field notes	Field notes and GPS locations of impact areas and substrate types can help with image interpretation.
Existing imagery	Recent photography and imagery from other sources such as the state DNR or Google Earth can provide references for change detection or additional geo-registration of the imagery.
Control points	GPS locations of prominent features can help with additional geo-registration of the imagery.

### Which Imagery Options to Purchase

How much to spend on a single image depends on your objectives. For use with other GIS data, the user probably wants the highest level of geo-rectification and processing affordable (lower level can be okay for simple image viewing or advanced users can do some of their own geometric processing). Depending on when the image is needed, the user may need to pay for expedited collection and processing. The user also can also decide if they want to buy multispectral, panchromatic, or pan-merged (see Fig. 2). Most satellites collect multispectral and panchromatic data simultaneously for all orders and the user should be able to purchase any of these products even after the data has already been collected.

Studies on coral and other substrate classification of satellite imagery have yielded few automated techniques for repeatable image analysis. Studies have been very successful at using on-screen digitizing by knowledgeable interpreters to produce high-level classification schemes for benthic communities (see <http://ccma.nos.noaa.gov/about/biogeography/>). Much less detail in substrate classification is required for an injury assessment, and it is likely that much information can be derived from a basic satellite image displayed on a computer and visually interpreted. The user might need only to purchase the pan-merged product to get the highest resolution color image or, if the resolution is fine, the user can just purchase the multispectral and view the natural color bands in their GIS software.

For any image processing the user will need to purchase multispectral imagery. The panchromatic can be purchased as well if higher spatial resolution is desired. There are a variety of image processing techniques that can improve image interpretation and classification (a good resource is the Remote Sensing Handbook for Tropical Coastal Management, <http://www.unesco.org/csi/pub/source/rs.htm>). Table 7 describes some advanced image processing steps that can be applied. These steps will probably require specialized image processing software, although popular GIS packages and add-ons may include some of this functionality (e.g. Spatial Analyst and Image Analyst for ESRI products). Basic steps for accessing imagery in a grounding situation are presented in Figure 3.

## Airborne Alternatives

Airborne sensors are advantageous in that they can produce very high spatial resolution imagery, can fly at user-specified times (avoiding factors like cloud cover), and can carry sensors currently not available on satellite platforms (see Table 8 for options). Digital aerial photography essentially uses the same types of sensors found in satellites, but mounted on an airborne platform. These sensors may collect in 4 bands or often can collect in 3 user-specified bands. In some cases, the sensors are independent of the platform and the contractor can mount them on any available aircraft.

Mission planning for airborne sensor systems is fairly similar to traditional aerial photography. The contractor should provide imagery that is distortion free (ortho-rectified), ready to use in a GIS (geo-rectified), in a standard file format that can hold information for multiple bands (like GeoTiff), and in a manageable number of files and file sizes (can request that the images be stitched together or mosaiced). Turn around times and costs for imagery can be competitive with satellite products even for small jobs. Again, an established relationship with a local or regional airborne imaging company can be advantageous.

**Table 7.** Image processing to assist in interpretation.

<b>Process</b>	<b>Description</b>	<b>Considerations</b>
Geo-registration	Imagery from the vendor may not line up with existing GIS data and may need additional local registration.	This is affected by the image processing level selected and the data that the vendor has to register the imagery. Ideally this process will not be necessary.
Statistical classification (supervised and unsupervised image classification)	Statistical techniques automate the grouping of image pixels based on their spectral band characteristics.	The user assigns the statistically similar groups to substrate or other classifications based on field knowledge or ancillary field data.
Change detection	Pre and post grounding imagery can be compared to look for differences in substrate or other classifications.	Ideally one would want to use classified imagery from different dates of the same sensor.
Image filters	Various types of image filters can highlight textural and contrast differences in the image to aid interpretation.	Generally less used. Could highlight things such as coral ridges or smooth vs. patchy substrate.
Band ratioing	Properties of some corals or substrates might result in predictable patterns of band reflectance (e.g. where Red is absorbed and Near Infrared is reflected you might have a predominance of seagrass).	Generally used for vegetation analysis. Techniques can also be used to model shallow (<30 m) bathymetry in clear-water environments (based on changing properties of reflectance as water depth increases).

**Table 8.** Alternative airborne sensor systems.

Sensor	Description	Considerations
Aerial film photography	Traditional mounted photography resulting in color or color Infrared prints.	Prints need to be scanned and converted to geo-rectified digital imagery.
Aerial digital photography	Mounted sensor acquires digital images often in the same 4 bands as the high resolution satellites.	Digital photography (and digitized film photography) can follow the same recommendations above for imagery interpretation.
Hyperspectral imagery	Acquires 10s to 100s of bands of data (as opposed to the 4 bands of the sensors discussed above).	Can provide more information in the water penetrating bands of the spectrum. Requires special software and more time to process.
LIDAR	Uses Laser range finding to produce a bathymetric/topographic map.	Can provide highly detailed depth information. Has depth range similar to imagery. Requires more time to process.

### Unmanned Aerial Vehicles

Unmanned aerial vehicles (UAVs) come in a wide range of sizes, configurations, and are generally costly to own and operate. Low-cost oblique photography has been achieved by mounting cameras to kites, helium balloons, and radio-controlled (RC) airplanes and helicopters. Recently there has been a trend towards small and affordable UAV systems using RC airplanes, stabilized cameras, and GPS units to acquire vertical imagery. This imagery can be ortho-rectified for use in GIS systems. Spatial resolutions are variable based on flight height but can achieve around a 15cm pixel size and cover around 200 acres in a flight. The RC airplanes vary but weigh less than 10 pounds with around an 8 foot wing span.

The RC airplane industry/hobbyist community is large and there are a variety of kits that can be purchased from various companies. The Cropcam ([www.cropcam.com](http://www.cropcam.com)) is a commercial RC UAV that has been specifically designed to compete with satellite imagery and traditional aerial photography for agricultural monitoring. Their products include the airplane, stabilized camera box, software, and hardware that allows for auto pilot following flight plan way points, and software for image distortion corrections and geo-rectification. Their package costs around \$7,000 with the user needing to purchase some additional equipment including the digital camera (or video camera if desired) and some RC components (both recommended to purchase locally for warranty and service reasons) that add an additional \$1,200. They also provide and recommend RC flight training which runs around \$500 for a 5 day course.

The Cropcam or a similar system should provide an image product that is no different than vendor purchased satellite imagery or photography (however this hybrid technology has been around for less than 2 years and it would be beneficially to demo some sample imagery in conjunction with existing GIS data). This type of platform would probably be the most cost effective due to the small area of vessel impacts (which would probably always be smaller than

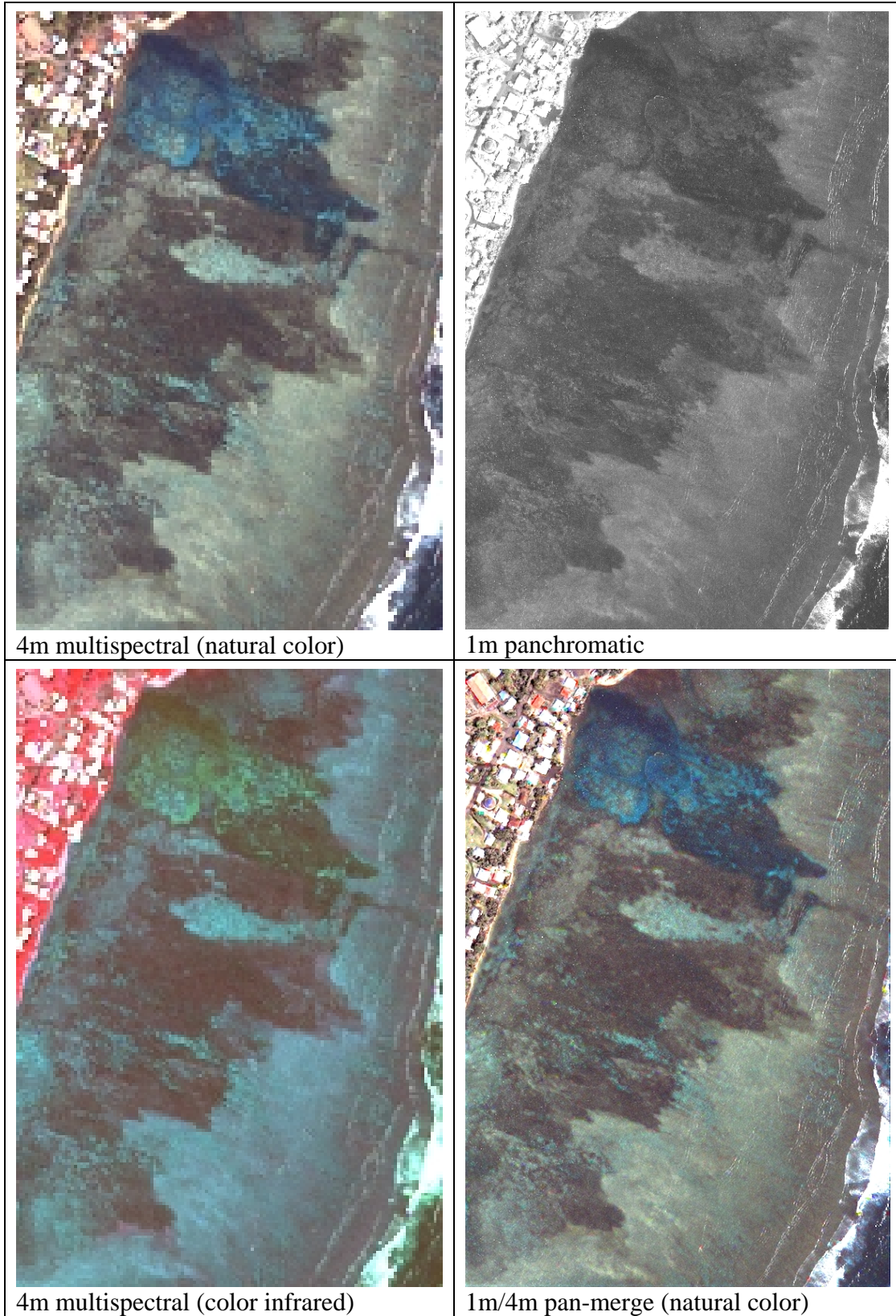
the minimum order size cost for imagery) and the high spatial resolution (15cm to half a meter). The big problem for water operations would be keeping the electronics dry and safely landing the aircraft. The Cropcam is hand launched and a sales representative claimed a good pilot can land it in a 60 by 60 ft area. RC helicopter style platforms exist but are noted by various sources as having a high rate of failure (i.e., falling out of the sky). There are also issues with FAA flight height regulations that would need to be checked locally and, as mentioned above, this technology is still new compared to satellite and aerial photography. The Cropcam group does not currently contract out for work and they were not aware of anyone using their product that does contract work. There are lots of contractors who use UAVs of various types for oblique photography but military and large government agencies seemed to be the only groups currently combining the UAV, GPS, and camera stabilization technologies to produce a true rectified vertical image needed for GIS applications.

## **References**

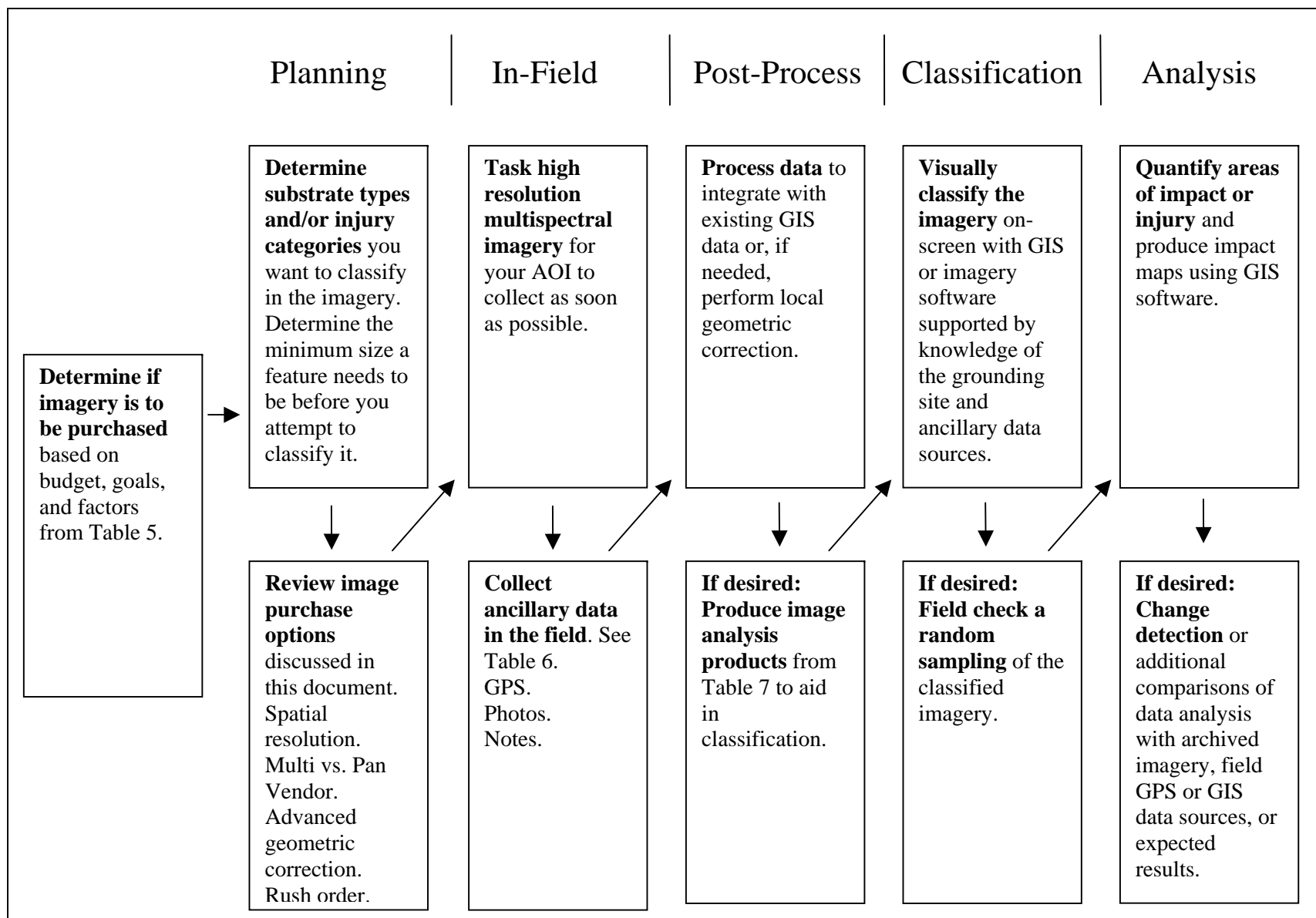
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**Figure 2.** Various imagery product options.



**Figure 3.** Basic steps and key points within those steps for using imagery to quantify injury in a grounding response.