HABITAT MAPPING

Habitat mapping objectives were defined as follows:

- create a baseline marine and terrestrial habitat inventory for the Cayman Islands,
- create a practical and repeatable mapping methodology,
- emphasise delineation of primary areas, especially delineation of dynamic habitats, such as *seagrass* in the marine environment, and *invasive coastal plants* on land,
- produce maps that would be at a level of detail of maximum benefit to the end user,
- utilise the abundance of existing supporting data.

Marine habitats (benthic, lagoons and shoreline habitats) were delineated using 2004 true colour aerial photography, supplied by the Cayman Islands Department of Lands and Survey, LS. The imagery was provided as both orthorectified and georectified to the local grid, in MrSID compressed format (scale 1:7,000, 0.12m resolution) in a projected UTM Nad27 datum based local coordinate grid, referred to as "CaymanLIS".

Terrestrial habitats were defined using 2006 Quickbird imagery, purchased by the *Department of Environment* DoE. Quickbird is multi-spectral (4 band) satellite imagery, with a resolution of 2.4m. Eight individual Quickbird satellite images comprised the necessary data coverage for the classification; four for Grand Cayman, two for Little Cayman, and two for Cayman Brac. All images were collected on different dates over the course of 2006. Images taken at different times of the year are subject to spectral variation, due to seasonal factors such as leaf growth and fall. As such, the composite image could not be classified using the automatic method, and each component had to be classified separately.

Marine Habitat Mapping

Marine habitats within and outwith lagoons were categorised separately, towards improving specificity for key features, such as seagrass beds and patch reefs, respectively.

Outwith lagoons, a hierarchical classification structure was used (following the example of a similar project, *Benthic Habitats of Puerto Rico and the U.S. Virgin Islands,* completed by NOAA's Centre for Coastal Monitoring and Assessment (CCMA)). The hierarchical structure allowed for expanding or collapsing the classification to suit specific mapping goals.

Development of the local classification scheme included extensive input from resource managers, experts on the Cayman Islands marine ecosystem, and the map producer, towards developing and adapting the hierarchical classification to suit local biogeographical conditions, and conservation management objectives. The end result of this evolving exercise was a scheme that was scientifically sound, practical and repeatable.

Habitat delineation outwith lagoons utilised the habitat digitizer extension for ESRI's ArcGIS desktop v9.x, developed for similar projects by NOAA's CCMA. It was important to determine a suitable scale when digitising; balancing the need to maximize the quality of the imagery, avoid becoming unnecessarily detailed or too generalized, and ensuring consistency in the finished product. For the current project a digitising scale of 1:2,000 was chosen for the majority of habitats. A scale of 1:500 was used when working with fine features which were difficult to map at the larger scale (such as beach rock and manmade docks). A minimum mapping unit (MMU) of 150 m^2 was selected, based on a combination of image quality, and the small size of some key habitats.

Approximately 1125 field validation points covering all three Cayman Islands were utilised in the mapping exercise. Generally a field crew of three was required to complete field validations which were undertaken prior to mapping (towards scoping and determination of mapping feasibility) and periodically throughout the project (to assess the quality of the mapped product). Additional field validations were undertaken in response to specific problem areas within the imagery, such as cloud cover. This was generally done using a "look-bucket" to determine habitat category at differentially corrected GPS coordinates.

Delineation of these habitats consisted of digitizing a polygon around unique areas visible in the 2004 aerial photography at a scale of 1:2,000 (when possible), selecting the associated habitat from the category scheme, and then finishing the polygon sketch. Adjacent areas of this polygon were then digitised in the same way until all of the imagery was assigned to the appropriate habitat category. Complementary imagery was referenced where necessary, particularly for areas missing or unclear in the 2004 aerials. When this failed to provide the necessary level of detail areas were visited and validated in the field.

In order to estimate and report the reliability of mapped results, an estimate of thematic accuracy was completed. This involved using 170 points distributed using a stratified random sampling approach based on habitat type and coverage (ha). An error matrix was then created and accuracy by category, as well as overall accuracy, was calculated. At the detailed level, thematic accuracy was determined to be ca. 77%, while at the general level accuracy was ca. 90%.

For habitats within lagoons, benthic habitat maps were created using a hybrid supervised classification / manual delineation technique. GeoTIFF files were used because, being uncompressed, they were able to be manipulated.

A habitat classification scheme was developed which met the benthic habitat mapping objectives and also complemented the scheme for non-lagoon areas. The classification consisted of; Sand, Vegetated Sand, Vegetated Mud, Seagrass, Uncolonised Hardbottom, Colonized Hardbottom, and Hard Corals.

ArcGIS polygon shapefiles were created to delineate all lagoon areas. These polygons were then imported into Idrisi 15.0, and used to 'clip' the imagery so that only lagoons were included in each classification. A 7x7 minimum filter was then applied to each image, to reduce the high incidence of sun glint and reflectance.

Due to the very high image quality, file sizes were too large for Idrisi to effectively render an automatic classification. To overcome this issue, the images were prepared for automatic classification using an aggregation (factor 10), so that the resulting pixels represented an average of 40 original pixels. This had the added benefit of 'smoothing' the appearance of the imagery. A supervised classification (maximum likelihood) was used for each lagoon. This was made possible by a combination of extensive local knowledge, copious habitat data from previous projects, and field verification data. Training areas were developed for each lagoon habitat. A maximum likelihood classification was completed for each lagoon and results were checked using field validation data.

A number of iterations of the classification were completed until a satisfactory image was created for each lagoon. It was not possible to include coral or rubble in the automatic classification due to the high incidence of spectral mixing. Manual image-interpretation of 2004 aerial photography was used to delineate coral and rubble.

Cloud shadow and sun-glint presented issues. These areas were minimal, but where present, extensive field validation and cross-referencing with other available imagery were used to obtain a complete mapped product.

Shoreline Habitat Mapping

A detailed shoreline classification was completed as a value-added exercise, to assist in coastal zone management and complement the existing National Oil-spill Response plan. Shorelines will be ranked in order of their sensitivity to oiling, and it is planned that this information will be used in combination with environmental and recreational-use data to create an Environmental Sensitivity Index (ESI) map. The ESI will assist coastal zone managers in identifying vulnerable locations, establish protection priorities, and identify cleanup strategies in the event of an offshore oil or chemical spill.

A classification scheme was developed based mainly on substrate size and permeability, presence (or absence) of a natural vegetation line, and dominance of substrates in a given area. The individual substrate types were ironshore, rock, sand, cobble, vegetation, and man-modified installations.

The shoreline, for the purposes of this project, was defined and delineated as the area between the high water mark and the natural vegetation line (where present). The best example of a natural vegetation line in recent years came from the 2004 pre-Ivan imagery, taken in April of that year, largely due to the impact that Hurricane Ivan had on shoreline vegetation in September of that year. Also, the excellent quality of the imagery allowed for a classification through image interpretation. An extensive field validation exercise was completed to ensure the validity of this approach.

The shoreline was divided into sections with distinct substrate qualities. In each section there was the possibility of having up to three substrate types. In areas where 'mosaic' substrates occurred and were oriented parallel to shore, the seaward substrate was mentioned first and up to two more substrates were then mentioned, based on proximity to the water. In areas where the substrates were oriented perpendicular to the water line, the most dominant feature was mentioned first and then remaining substrates were mentioned in order of dominance. In areas where the natural vegetation line occurred at or beyond the high-water mark (i.e. mangrove), no shoreline was given and this area was mapped within the terrestrial habitat mapping project.

Terrestrial Habitat Mapping

Terrestrial land cover / land use maps were created using a hybrid automatic classification / manual delineation technique.

A hierarchical classification system was developed for the terrestrial habitat maps (see following section). Each mapping objective was first analyzed and the appropriate method was considered. After running an automated unsupervised classification (cluster), areas of spectral mixing were highlighted and analyzed using field validation data and local knowledge. This information was used to determine which methods would achieve the mapping objectives most effectively.

The first step was to determine which data would be masked in a supervised classification. Masked data were as follows:

- offshore areas and shoreline (for which separate classifications were already completed),

- nearshore vegetation (coastal shrubland was too similar in spectral reflectance to other habitats and inclusion of these data would obscure patterns in the remaining data),
- invasive Weeping willow *Casuarina equisetifolia* and Beach naupaka *Scaevola sericea* (for which a manual delineation was completed because of their particular importance as invasive species),
- cloud and cloud shadow,
- buildings (for which there are up-to-date polygon shapefiles that accurately reflect position and coverage better than possible using an automatic approach),
- roads (because of the availability of accurate data in shapefile format), and
- obviously built up areas (of which it was decided to use an object-oriented approach as it unnecessarily obscured patterns in remaining data).

Once suitably masked images were prepared, a supervised classification (maximum likelihood) was completed for each image. Requisite validation data were acquired through field observations, and aerial photo interpretation using very-high resolution aerial photography from a similar time frame. Approximately 125 field validation points were visited, each with a habitat category assignation, photos, and comments recorded.

Some observations were completed before the first attempt at the classification and some were taken at areas that were difficult to accurately classify due to cloud and cloud shadow, excessive spectral mixing, and obvious errors based on personal experience. It was not always possible to physically visit a location where problem areas occurred due to their inaccessibility, and in these cases all attempts were made to use a 'best guest' by local ecologists using aerial photography interpretation and personal experience.

Areas where feature discrimination and spectral mixing were an issue were noted. One main area of difficulty was between wetland and dry forest habitats. In order to attain the highest possible accuracy in boundaries between wetland and forest areas, all wetland area boundaries were delineated using aerial photo interpretation with reference to previously compiled detailed Swamps and Shallow Marine Substrates Maps, prepared by Overseas Development Natural Resources Institute, 1987. These maps accompanied the publication *Biogeography and Ecology of the Cayman Islands (D.R. Stoddard, M.A. Brunt and J.E. Davies* All previously mapped wetlands were compared to current data and this information assisted the delineation of boundaries. All new or previously unmapped wetlands were then delineated.

Nearshore vegetation was simply masked, and built-up areas were delineated. The majority of vegetation fell within one of the following classes: coastal shrubland, dwarf shrubland, Casuarina, or Scaevola categories. These were generally easier to delineate manually, rather than classify automatically.

Areas of cloud and cloud shadow within the imagery were manually digitised using photo-interpretation (multiple images), and information gathered from the surrounding automatic classification data.

Casuarina equisetifolia was identified as a species of key significance, due to its invasive nature. The ability of the 2004 imagery to very accurately distinguish this tree species enabled their mapping using photo interpretation and digitization. The same was true for the invasive *Scaevola sericea*. The same method was used to delineate this species. Aside from being included in the terrestrial habitat maps, this information will be used independently of the project to inform management decisions.

A mosaic of all data layers was compiled to form a single complete classification image for each island. This method proved to be robust in its added accuracy, its ability to meet mapping goals, and the marginal increase in time necessary to complete. It also made it possible to focus more on accurately classifying natural areas and less on unnecessary variability within the images.

These maps are considered dynamic documents and, as such, will be regularly updated (with all originals saved for reference and comparison), focusing on specific areas as necessary, in response to specific projects, as well as tracking development of natural and successional areas. The terrestrial habitat maps will serve as a detailed baseline land cover / land use resource for the Cayman Islands, providing decision

makers and managers with accurate baseline and trends information towards better informing land use planning and management and implementation of effective strategies for biodiversity protection.

HABITAT CATEGORIES:

An integral component of the *National Biodiversity Action Plan* is the mapping of the diversity of habitats of the Cayman Islands. This ambitious project was undertaken by staff of the *Department of Environment*, with the assistance of Frederic J. Burton.

At the highest level, habitat categories are broadly divided into Marine, Coastal and Terrestrial.

Marine habitats were subdivided and categorised in part, based on a similar project: *Benthic Habitats of Puerto Rico and the U.S. Virgin Islands,* completed by NOAA's Centre for Coastal Monitoring and Assessment (CCMA).

Coastal and terrestrial habitats were subdivided, and categorised according to the *Vegetation Classification* formations of Burton (2008b), with supplementary categories for man-modified environments.

Habitat distinctions are made by way of facilitating a logical treatment of the habitats of the Cayman Islands, and should not be taken as indicative of isolation of ecological function or independence. To some extent, all elements of biodiversity are fundamentally interlinked.

MARINE HABITATS

CATEGORY

1. Open sea defined as all *marine habitats*, including the seabed and benthos, the water column and pelagic zone, and the water surface, which extend beyond the fringing reefs which surround the Cayman Islands, and which fall within the Cayman Islands EEZ. *Open sea* incorporates the deep sea, offshore waters, and *"nearshore waters"*, defined as those within a twelve-mile radius of the fringing reefs around the islands.

2. Coral Reefs defined as limestone formations produced by living organisms. Corals are found both in temperate and tropical waters; however, shallow-water reefs are formed mostly within the zone between 30° north and 30° south of the equator. Incorporates, the following formations:

- Aggregate reef: defined as areas where hard coral cover (alive & dead) exceeds 70% substrate coverage. Usually found in the bank / shelf area, and / or the escarpment. Some soft corals / sponges may also be present.
- Spur and groove: defined as feature, typically hard coral cover (alive & dead), exhibiting a high vertical relief relative to the surrounding pavement / sand channels. "Spurs" are usually formed by accreting hard corals. "Grooves" usually comprise sand and / or hardbottom. Spur and groove features are usually associated with the seaward edge of the reef crest, and with the edge of the fore reef, near the escarpment, orientated perpendicular to shore and escarpment. Some soft corals / sponges may also be present.
- Individual patch reef: defined as isolated coral formations. Hard corals generally dominate, although some soft corals and sponges may be present. Only patch reefs greater than the MMU feature in habitat maps.
- Aggregated patch reef: defined as aggregated coral colonies, where colonies exhibit > 70% substrate coverage. Hard corals generally dominate, although some soft corals and sponges may be present. Confined areas of bare sand or hardbottom are present within the matrix of the reef aggregation, and are incorporated into the mapping delineation
- Reef rubble: defined as dead, unstable coral rubble and rocks. Reef rubble is often colonised with filamentous or other macroalgae.
- Reef crest: defined as a semi-emergent to emergent high points of coral reef.
- Sand plain: defined as an expanse of uncolonised sediment (ranging from course sand to silt) located between the shallow and deep terrace reefs.

- **Colonised hardbottom:** defined as pavement exhibiting coral cover within the range of 10-70% of the substrate. Dominant features are low-relief pavement or rubble, or low-relief rock and sand grooves, colonised by algae, soft corals, and sparse hard corals, which are dense enough to partially obscure the underlying rock. Where coral cover >70%, areas fall within the *aggregate reef* category.
- **Uncolonised hardbottom:** defined as pavement, often dominated by algae but exhibiting a hard coral, soft coral, and sponge cover of <10%.
- **Wall:** near-vertical or vertical slope extending from the shelf-margin to abyssal depths and characterised by abundant coral and sponge colonisation from the drop-off to 120 m.
- **Beachrock:** defined as cemented sand. Beachrock is derived from calcite precipitating out of seawater; resulting in the formation a flat rock-like substrate.

3. Lagoons defined as nearshore reaches of shallow salt or brackish water, separated from the *open sea* by a shallow or exposed *coral reef,* banks, or similar feature. Incorporates, the following formations:

- **Seagrass beds:** defined as areas where seagrass species represent the dominant substrate coverage. In cases where algae and seagrass co-exist, coverage is designated as *seagrass beds* if seagrass is dominant, and to the *vegetated sand* category if algae is dominant. *See also separate Seagrass beds HAP.*
- **Sediment:** unvegetated mud and sand.
- **Hardbottom:** low-relief pavement or rubble, or low-relief rock, often colonised by algae.
- **Vegetated sand:** vegetated sediment ≥1 mm in diameter.
- **Mud:** bare or sparely vegetated sediment <1 mm in diameter.
- **Lagoonal coral**
- **Backreef:** defined as dead, unstable coral rubble and rocks located on the landward side of the fringing reef / reef crest. Reef rubble is often colonised with filamentous or other macroalgae.
- **Beachrock:** defined as cemented sand. Beachrock is derived from calcite precipitating out of seawater; resulting in the formation a flat rock-like substrate.

4. Seagrass beds defined as areas where seagrass species represent the dominant substrate coverage. In cases where algae and seagrass co-exist, coverage is designated as *seagrass beds* if seagrass is dominant, and to the *lagoons, vegetated sand* category if algae is dominant.

5. Dredged seabed defined as any area of lagoon, inshore waters, reef or shallows, which has been modified as a result of channelisation, coastal development or dredging for fill.

6. Artificial installations defined as maritime constructions, including docks, large piers, and groynes. This category also includes underwater structures such as shipwrecks, underwater sculptures, and artificial reef structures.

COASTAL HABITAT CLASSIFICATIONS:

7. Maritime Cliffs and Ironshore defined as consolidated rocky coastal areas, between the limits of the high water mark on the seaside, and the natural continuous vegetation line on the landside. Incorporates the VII.A.1.N.a vegetation formation, as *per* Burton (2008b):

- Cliffs with sparse vascular vegetation VII.A.1.N.a – vegetation of shaded cliffs, supports *Verbesina caymanensis*, restricted to north-facing section of bluff near Peter's Cave, Cayman Brac
- Maritime cliffs
- Ironshore
- Ironshore mosaic – shoreline comprising mostly ironshore, with one or more other substrates
- Beach rock
- Beach rock mosaic – shoreline comprising mostly beach rock, with one or more other substrates

8. Sandy beach and cobble defined as all unconsolidated coastal sediments, between the limits of the high water mark on the seaside, and the natural continuous vegetation line on the landside.

- Sandy beach
- Sandy beach mosaic – shoreline comprising mostly sandy beach, with one or more other substrates
- Cobble
- Cobble mosaic – shoreline comprising mostly cobble, with one or more other substrates

9. Mangrove defined as habitat and plant assemblages associated with Black mangrove *Avicennia germinans*, White mangrove *Laguncularia racemosa*, Red mangrove *Rhizophora mangle*, and Buttonwood *Conocarpus erectus*. Incorporates the following vegetation formations, as *per* Burton (2008b):

- Seasonally flooded evergreen sclerophyllous forest I.A.5.N.c
- Tidally flooded mangrove forest I.A.5.N.e
- Seasonally flooded / saturated sclerophyllous evergreen woodland II.A.1.N.i
- Tidally flooded evergreen woodland II.A.1.N.e
- Seasonally flooded / saturated evergreen shrubland III.A.1.N.f
- Saturated sclerophyllous evergreen shrubland III.A.1.N.h
- Tidally flooded evergreen shrubland III.A.1.N.i

10. Invasive coastal plants defined as the species / monoculture habitats of Weeping willow (Casuarina, Beefwood, Whistling pine, Australian pine) *Casuarina equisetifolia* and Beach naupaka (Sea lettuce, Scaevola) *Scaevola sericea*. Incorporates the following vegetation formations, as *per* Burton (2008b):

- Needle-leaved evergreen woodland II.A.3.C.a

11. Coastal shrubland defined as a class of vegetation dominated by flora which ranges in height between 0.5m and 5m. Shrubs tend to grow as separate individuals or clumps of individuals. In *shrubland*, the canopy cover of shrubs constitutes greater than 25% of the total canopy cover. Larger trees may be present in *shrubland;* however, tree canopy cover should constitute less than 25% of the total cover to distinguish the area from "woodland". Incorporates the following vegetation formations, as *per* Burton (2008b):

- Hemi-sclerophyllous evergreen shrubland III.A.1.N.b
- Sclerophyllous evergreen shrubland III.A.1.N.c
- Mixed evergreen / drought-deciduous dwarf-shrubland IV.C.1.N.a
- Low tropical / subtropical perennial forb vegetation V.B.1.N.b

TERRESTRIAL HABITAT CLASSIFICATIONS:

12. Salt-tolerant succulents defined as areas of succulent-dominated forb vegetation (non-woody plants other than grasses, sedges and rushes) influenced by regimes typically of high salt, and temporary or occasional water immersion. In coastal areas, this may include tidal areas, or those influenced by the tide. Further inland, this habitat forms in association with temporarily flooded pastures, and moderately elevated rocky cays, often at the edges of wetlands and *mangroves*. Incorporates the following vegetation formations, as *per* Burton (2008b):

- Tidally flooded perennial forb vegetation V.B.1.N.e
- Tidal tropical or subtropical annual forb vegetation V.D.1.N.d. (NOTE: Due to the aquatic nature of this habitat, it is also listed under *pools, ponds and mangrove lagoons*).

13. Pools, ponds and mangrove lagoons defined as natural and man-modified areas of standing permanent and temporary water and associated vegetation, including pools, ponds, ditches and flooded marl pits. This habitat category incorporates both natural areas, and manmade ditches and flooded marl pits. Natural

freshwater pools are a rarity in the Cayman Islands, and of key conservation interest. With appropriate management, the ecological value of man-modified water features can be greatly increased.

- Semi-permanently flooded grasslands V.A.1.N.h.
- Aquatic vegetation V.C.1.N.a.
- Tidal tropical or subtropical annual forb vegetation V.D.1.N.d. (NOTE: Due to the vegetation component of this habitat, it is also listed under *salt-tolerant succulents*).
- Mangrove pools and ponds
- Mangrove lagoons
- Flooded marl pits

14. Dry shrubland defined as a class of vegetation dominated by flora which ranges in height between 0.5m and 5m. Shrubs tend to grow as separate individuals or clumps of individuals. In *shrubland*, the canopy cover of shrubs constitutes greater than 25% of the total canopy cover. Larger trees may be present in *shrubland*, however, tree canopy cover should constitute less than 25% of the total cover to distinguish the area from "woodland". Incorporates the following vegetation formations, as *per* Burton (2008b):

- Tropical or subtropical broad-leaved evergreen shrubland III.A.1.N.a
  - Incorporating Black candlewood *Erithalis fruticosa* alliance III.A.1.N.a (1)
- Mixed evergreen-drought deciduous shrubland with succulents III.C.1.N.a

15. Forest and woodland defined as a class of vegetation characterized by a closed tree canopy, with interlocking crowns generally providing 60-100% cover. "Woodland", by comparison, is characterised by an open canopy, with tree crowns constituting just 25-60% cover. The canopy height of *forest and woodland* ranges from about 16m, down to about 4.5m in height, below which *shrubland* species dominate. Incorporates, the following vegetation formations, as *per* Burton (2008b):

- Lowland semi-deciduous forest I.C.1.N.a
- Seasonally flooded / saturated semi-deciduous forest I.C.1.N.c
- Xeromorphic semi-deciduous forest I.C.4.N.b
- Lowland / submontane drought-deciduous woodland II.B1.N.a
- Tropical or subtropical semi-deciduous woodland II.C.1.N.a

16. Caves defined as erosional landforms, including pot holes and fissures, which form as a result of wave action, or the action of rain and underground water courses.

17. Farm and grassland defined as any land which is activity managed for agricultural purposes, or comes under the influence of agricultural practice, specifically, the growing of fruits, crops or the keeping of livestock. Incorporates, the following vegetation formations, as *per* Burton (2008b):

- Seasonally flooded grasslands V.A.1.N.g
- Medium tall tropical/subtropical grassland with broad-leaved evergreen or semi-evergreen shrubs V.A.3.N.c
- Short tropical or subtropical grassland with broad-leaved evergreen or semi-evergreen shrubs V.A.3.N.f
- Saturated tropical or subtropical perennial forb vegetation V.B.1.N.d
- Agricultural plantation

18. Urban and man-modified areas defined as the populated areas of the Cayman Island, and those areas of land subject to direct modification by man.

- commercial and residential areas on the islands, incorporating town centres, industrial sites, hotels and condominiums, and private homes and residential developments
- public and private green-space, such as parking lots, landscaped areas, parks and recreation grounds, cemeteries, and private gardens

- land cleared for development
- actively farmed land
- historically cleared areas, now reverting to nature, and exhibiting secondary growth
- roads are a component of this landscape, and are also assigned an individual *Roads* HAP.

19. Roads defined as the public and private roads network. *Roads* incorporates surfaced and unsurfaced roads and associated landscaping and infrastructure, including roundabouts, mediums, sidewalks, drainage conduits, roadside verges and pathways.

REFERENCE:

Burton, F.J. (2008b) Vegetation Classification for the Cayman Islands. In: Threatened Plants of the Cayman Islands: The Red List. Royal Botanic Gardens Kew: Richmond, Surrey UK