The Undulate Ray Project

Identifying individual fish at a ray hotspot along the Dorset coast

Status Report, March 2018

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Cover image
Undulate ray near Kimmeridge, Dorset

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Summary

Undulate rays (*Raja undulata*) seem to be thriving along parts of the south coast of the UK, even though they are listed as endangered on the ICUN red list. Little is known about their habits and movements in the wild, the discovery of a 'hot spot' on the Dorset coast some five years ago gave the opportunity to study this enigmatic species. The *Undulate Ray Project* started with the photographic identification of individual undulate rays and monitoring the site confirmed that they remain or return to very local areas. The Undulate Ray Project is now gathering data from anglers and divers to learn more about the lifestyle and movements of individual undulate rays.

At the study site over a dozen rays can often be seen during a single dive, particularly after the black bream cease their spawning activity in early summer, but generally throughout the year. From photographing the rays it became apparent that a small number of fish with distinctive markings could be identified from more than one occasion, even across years.

Plate 1: An undulate ray off the Dorset coast.

A methodology has been established by the team for recognising individual rays using images of their unique dorsal pattern of dots and lines. The method uses peer-reviewed software, freely available online, to provide accurate and scientifically verifiable identification of individual fish. The project's Initial findings and the potential for further work on this site provided the opportunity to investigate site-fidelity and local migrations of this species and explore possible reasons that so many fish use and return to the site e.g. potentially for feeding, resting or breeding.

A photographic catalogue of over 100 individual undulate rays had been established for the main Dorset site prior to 2017, providing a unique and robust data-set upon which to build. The catalogue was extended to include 248 individual undulate rays during 2017 and now provides a central core of information for comparison with other sites.

During 2017 the project team gathered considerable support from the diving and sea angling communities by way of asking individuals to submit their own images and sighting data that conformed to the project requirements. A website was developed (www.undulateray.uk) to

promote the project and allow people to get involved by submitting their sighting data and images. Video and photographs have been used to facilitate the project outreach to the wider diving and angling communities within Dorset and neighbouring counties via a range of presentations and social media outlets. Furthermore, an image taken by Matt Doggett in August 2017 on the day of the British and Irish Underwater Photography Championships run by the British Society of Underwater Photographers (BSOUP) was Highly Commended and helped generate further publicity for the project.

The *Undulate Ray Project* has also collaborated with a genetics research project at the University of Manchester run by Samantha Hook. Our project presents a rare and sustainable opportunity to obtain genetic material *in situ* in a harmless way (using swabs) rather than the traditional method of using fished animals; over 50 samples were collected in 2017. The genetics project uses genetic markers to understand the structure of the existing known population of undulate rays and assess concerns regarding overfishing of the species. Analysis of our samples will add to this understanding and might also identify any local relationships between the fish known to *The Undulate Ray Project*.

The response to *The Undulate Ray Project's* Outreach Program has been tremendous; 88 people have contributed images bringing the number of ray recordings to over 600 and the photo catalogue to over 500 individual fish, 59 of which have been seen on two or more occasions. Although at this time, only a preliminary analysis has been done, the data support the known tendency toward high site-fidelity of undulate rays with all repeat sightings of individuals occurring at the same locations. The distribution of sightings along the coast is unlikely to represent the distribution of undulate rays, it being largely influenced by favourite angling and diving locations together with the focus of the Outreach Program (Poole and Weymouth). The sightings are concentrated in four locations, Chesil Cove, Swanage, Boscombe and the original study site at Kimmeridge.

The project is on-going. The data are still being analysed, the DNA testing needs to be finished and people continue to submit their photographs adding to the dataset. The video footage and still images were due to be used in the BBC2 show Hugh's Wild West; unfortunately, the number of episodes in the initial series was reduced and the story did not make the final cut although the Black Bream Project did feature in Episode 2! In 2018 we hope to focus on areas closer to the original study site and supplement the data with further observational information that will add to the understanding of undulate rays' natural history and behaviour.

Introduction

Project team members are Martin Openshaw, Sheilah Openshaw, Matt Doggett, Polly Whyte, Lin Baldock and Samantha Hook.

The undulate ray (*Raja undulata*) is a Species of Principal Importance in England and Wales. Globally the species is listed as Endangered on the IUCN Red List whilst its status in European waters is 'Near Threatened'[1]. Despite these classifications the species can be locally common where it occurs. Previously over-exploited, undulate ray numbers have declined rapidly since the 1980s by up to as much as 80% in some areas leading to a no-catch policy being introduced across the European Union in 2009. Recently however, sightings and catches are on the increase, particularly along some areas of the UK coast, including Dorset and quotas have been slowly reintroduced into the fishing community since 2015[2].

The distribution of undulate rays extends from Morocco and the Mediterranean, north to Portugal, the Atlantic coast of France and into the English Channel and Southern Ireland. They are known to be locally common in patches distributed along the English Channel including Sussex, Poole, around the Isle of Wight, Lyme Bay and the Channel Islands[3]. The degree of isolation of the remaining populations and resulting impact on genetic variation is unknown. Low migratory tendencies and a lack of genetic variation can prevent adaption to environmental change and/or cause individuals or populations to be more susceptible to disease.

The undulate ray can grow to around 1m long with an observed maximum age of 13 years. Estimates suggest that undulate rays might live to around 20 years though individuals of this age have not been recorded, much of the data being derived from aquaria. Fish do not mature until 7-9 years of age[4]. Observations suggest a degree of site-fidelity in the species; a potentially important characteristic for its conservation.

Despite the species' protected status, relatively little is known about its breeding or migratory habits in the wild. This project aims to fill some of those knowledge gaps by concentrating diving effort on Dorset sites and complementing that with other information. The project ultimately aims to enhance the understanding of how the fish use the sites surveyed by locating live egg cases or observing feeding or mating; these objectives are still on-going.

Undulate rays are not shy fish and can be approached by divers with ease to obtain suitable identification photographs. Using photographic recognition as a non-intrusive alternative to conventional tagging, a database of ray sightings with recognition photographs has been accumulated and used to investigate site-fidelity at this location. The data clearly show that individual rays return 'home' even after prolonged periods.

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[1] Ellis, J.R., McCully, S. & Walls, R.H.L. 2015. *Raja undulata*. The IUCN Red List of Threatened Species 2015: e.T161425A48909382. Downloaded on 16 January 2018.

[2] ICES 2016. Undulate ray (*Raja undulata*) in divisions 7.d and 7.e (English Channel). ICES Advice on fishing opportunities, catch, and effort Celtic Seas Ecoregion. ICES Advice 2016, Book 5. Available online at http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2016/2016/rju-ech.pdf

[3] Ellis, J. R., McCully, S.R., and Brown, M.J. 2012. An overview of the biology and status of undulate ray *Raja undulata* in the north-east Atlantic Ocean. Journal of Fish Biology (2012) 80, 1057–1074.

[4] Cuelho, R. and Erzini, K. 2006. Reproductive aspects of the undulate ray, Raja undulata, from the south coast of Portugal. Science Direct Fisheries Research 81 (2006) 80-85.

In addition to gathering a comprehensive data set of our own, in 2017 *The Undulate Ray Project* Outreach Program asked other divers, anglers and fishermen for photographs to help establish where the rays might travel to when not at 'home'. These photographs, from varied sources, provide additional data on the distribution of the undulate ray and their site-fidelity. The additional images have greatly increased the size of the dataset available to the project and provide comparison data for the main site.

A conference presentation in 2016 established a connection with PhD student Samantha Hook at the University of Manchester and led to the project's input into a genetic study of the world population of undulate rays. *The Undulate Ray Project* provides a rare and sustainable opportunity to obtain genetic materials in a harmless way, rather than the traditional method of using fished animals. A methodology has been established and *The Undulate Ray Project* has collected DNA samples from wild rays on the original study site.

Plate 2: Distinctive markings on the dorsal surface allow individual fish to be identified with confidence.

Plate 3: Undulate rays are not shy fish and can be approached with ease to take a photograph.

The Kimmeridge study site

The site forms part of Kimmeridge Ledges; a series of shallow ledges reaching out to sea for up to a mile. These have caught many a sailor unaware, causing numerous shipwrecks. Each pair of ledges forms a wide shallow valley with the whole series providing a variety of habitats for sea life. The study site is approximately 50-metres wide and over 200-metres from north to south. Although the site is an extremely small area of the overall south coast (being roughly the size of two football fields) it is an extensive area to cover comprehensively by diving. The site has provided an opportunity to observe multiple undulate rays in their natural environment; we are not aware of existing records for similar dense aggregations of undulate rays in such a specific location.

The rays are found resting on the seabed and although a few might be skittish and dart or more likely, gracefully swim away as a diver approaches, most are comparatively placid and can be approached with care. In almost all cases where an undulate ray is seen, it is possible to get very close, photograph the fish and either, place a photographic scale close by to give an indication of size, or obtain a mucus DNA sample with a pre-prepared swab.

Prior to 2017 we had dived the site specifically looking for rays, approximately 10 times each year from mid-2012. During this period, we recorded 201 encounters with rays, including spotted and thornback rays but most sightings (166) were of undulate rays. This was a surprisingly high proportion of undulates and we were able to get suitable images for identification purposes for 151 of the sightings. When suitable photographs could not be obtained it was often because the rays had buried or partially buried themselves meaning there was insufficient pattern visible to positively identify them. When all 151 images were analysed, 107 individual undulates were identified, 44 of the photographs being repeat sightings of rays identified in the 107. Some of the 44 repeats were seen several times, one ray for example being seen on 5 separate occasions. Of the 107 identified individuals, 25 were seen on two or more days, giving an approximate 23% repeat sighting rate to the site.

Increased diving activity during 2017 considerably extended the data for the site. This was achieved by increasing both the number of visits and the members of the dive team. When we started to gather DNA samples in August, diving was limited to two pairs of divers per day to avoid putting undue stress on rays or the site. Of the total 351 sightings of rays, 311 were undulate rays and identification photos were obtained from 248 of these encounters.

Sightings of rays (2012-2017) = 351
311 undulate rays (*Raja undulata*)
29 spotted rays (*Raja montagui*)
7 thornback rays (*Raja clavata*)
1 small-eyed ray (*Raja microcellata*)
3 not identified

When analysed, 179 individual undulate rays were identified, with 69 photographs being repeat sightings. 25% of the identified individuals (45) have seen on more than one day, and 22 of these on more than one year.

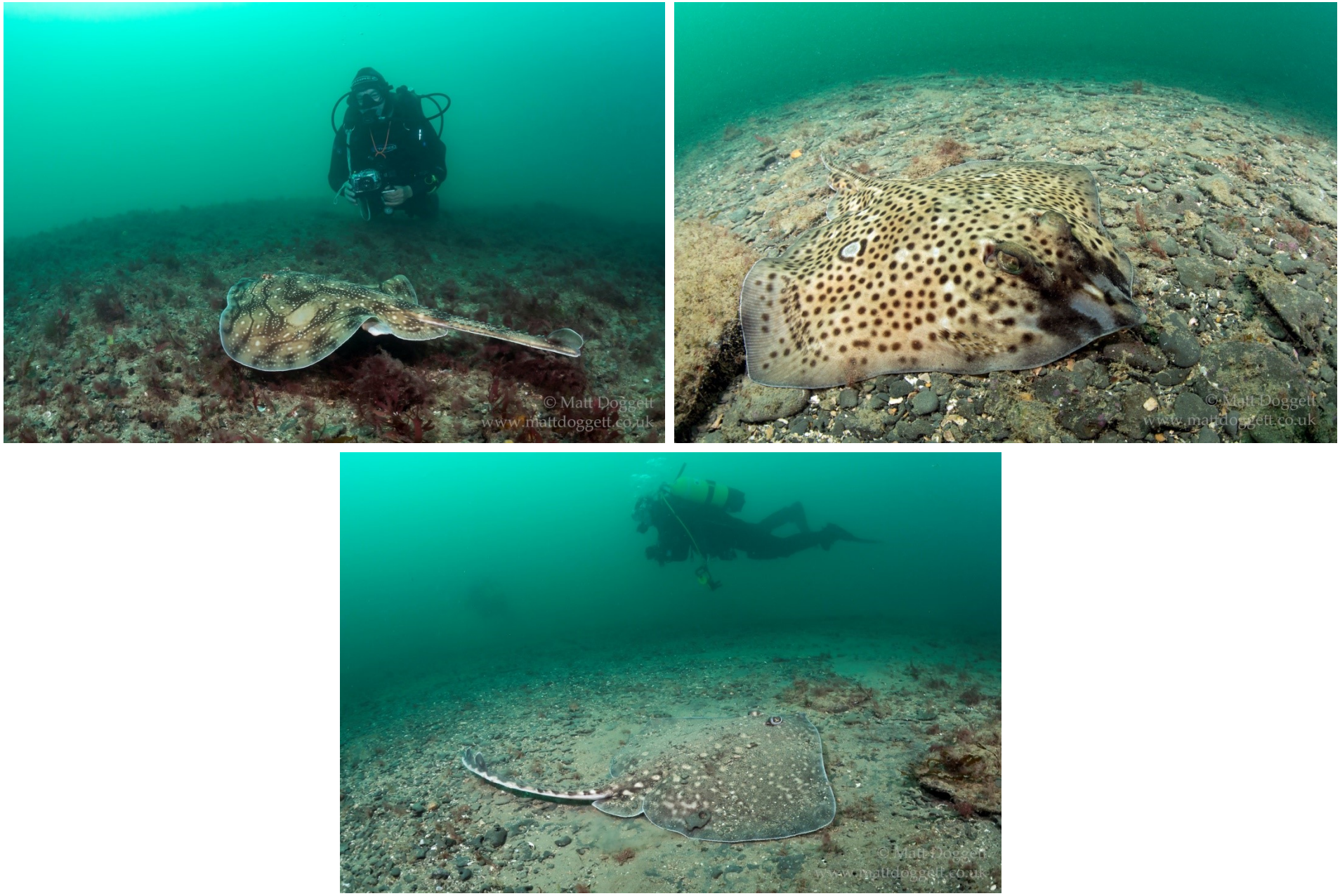

Plate 4: Some the ray species recorded from the Kimmeridge site. Clockwise from top left: undulate ray, spotted ray, thornback ray.

Repeat sightings of the same rays occurred either days, months or years apart. We have not recorded the same fish on many occasions although “Billy” remains our most frequently seen individual, having been photographed five times. The infrequency of single individuals being seen more than twice suggests the rays may visit the area on a periodic basis. Twenty-five percent of the overall rays were seen on repeat occasions, often after two or three years. This suggests the overall population visiting the site on a regular basis is limited.

Diving on the site has only been undertaken during daylight hours when the rays are found resting on the seabed. It is rare for a diver to come across a swimming ray although several swimming rays have been captured on remote video cameras when divers are not present. A swimming ray is likely to be much more aware of an approaching diver than the diver is of the ray, and take avoiding action swimming around the diver just out of visibility range.

The site, in a shallow depression between two ledges is subject to relatively low tidal flows especially close to the seabed. The seabed consists of a mixed layer of sand, gravel and broken shale over shale bedrock. Against this background the pattern of wavy lines and white dots on the undulate ray provides an excellent disguise, allowing them to blend into the surrounding seabed. The rays will often partially bury themselves with broken shale and gravel, and unless a diver is specifically looking for them it is very easy to swim directly across a ray without seeing it. Rays have been photographed independently by different divers in the same position several hours apart. Later, close examination of both photographs shows the ray to be in exactly the same position relatively to adjacent boulders and weeds, and the same pieces of shale to be on the surface of the ray. It is clear from this information that at least some of the rays rest in the same position on the site for several hours. It is possible that the rays favour the conditions on this site to rest during the day.

Recognising individual undulate rays

The pattern on the upper surface of an undulate ray is unique in the same way a human face or fingerprint is individual and recognisable. The pattern remains the same over the ray's lifetime; although the overall size may change as the ray grows from juvenile to adult, the overall pattern of wavy lines and dots will remain the same. The pattern is also not completely symmetrical; the asymmetry is the basis for the recognition process. In 1926, commenting on the size and shape of undulate rays, Robert Selby Clark[5] reported that *"In the examination of thousands of Rays, I have never met with examples which have been perfectly symmetrical."*

Initially developed as a manual process, the visual assessment of asymmetric features remains the key technique to identify photographs of matching individuals. However the use of recognition software became essential as the number of fish in the database grew.

Photograph suitability

Obtaining a good quality image is not essential, it is much more important to get the full width of the ray in the frame of the photograph. This allows a comparison of the pattern and especially the asymmetry of individual markings on the fish. The best images for identification are taken from directly above. The ideal photograph will have the whole width of the fish and nothing but the fish. The tail is less important for recognition unless it has unusual markings. Factors that reduce the value of a photo for recognition are: -

- Camera flash reflections - bright reflections or backscatter in underwater images will be interpreted as pattern by the computer system. A dark, natural light photo may be better than using flash.
- Curvature because the fish is not on a flat background. The software uses a 2-dimensional analysis and fish held vertically in mid-air have sufficient curvature to disrupt the pattern-matching process.
- Oblique images or fish not on a flat background - the software uses a 2-dimensional analysis, a certain amount of perspective is OK, but it downgrades the recognition process.
- Stones, weed or other foreign objects that obscure the part of the pattern.
- Poor image resolution normally because the camera is not close enough to the fish.

Pre-processing of photographs

Comparison of images and recognition of individual fish is much easier if the photographs are first processed to the same size, colour format and orientation. The image is first converted to black and white because colours, especially from underwater photographs can be very misleading. Each image is rotated to position the snout at the top, cropped to the width of the wings and resized to consistent dimensions. The aim is to get the body and wings of the fish filling the image; the tail is considered of lesser importance for individual identification. If the photograph was taken other than looking directly down on the fish, some perspective correction may be applied however there is a limit to the effective correction that can be applied without distorting the image. Adjusting both

[5] Clark, R.S. 1926 Rays and skates: a revision of the European species. HMSO publication 1926.

brightness and contrast can sometimes enhance the pattern on the fish significantly. The background is erased or masked otherwise the algorithm includes it in the recognition process.

Computer photo recognition

Once the images are processed the most likely matches are identified for each photo using the software application, “Wild-ID”. This is freely available for non-commercial use, as a download from the website of Dartmouth College, Hanover, U.S. The software compares each new image against previously stored images before displaying and providing a numerical matching coefficient for the 20 most likely matches. Using images showing the entire dorsal surface of the fish has proved most successful, rather than isolating an area or feature. This also has the advantage that images where parts of the pattern are obscured can still be compared.

Where the dorsal pattern is clear the software can identify images of the same fish and discriminate them with a higher numerical matching coefficient. Where the dorsal pattern is partially covered or obscured by lighting reflections, matching images are discriminated less clearly and other images of the same fish may not have the highest matching coefficient. In these cases, with all the images the same size, format and orientation it is relatively easy to scroll through the twenty likely matches and identify the most promising potential matches.

The recognition process

The final decision on whether two images match is a manual observation, comparing sections of pattern between two images be it on the body, wings or tail. Differences are compared between left and right dorsal areas of the fish to ensure these same differences occur on both photographs. Where the same fish is in two separate images the similarity becomes striking. Conversely if there is doubt when comparing two photographs, these will not be considered as the same fish.

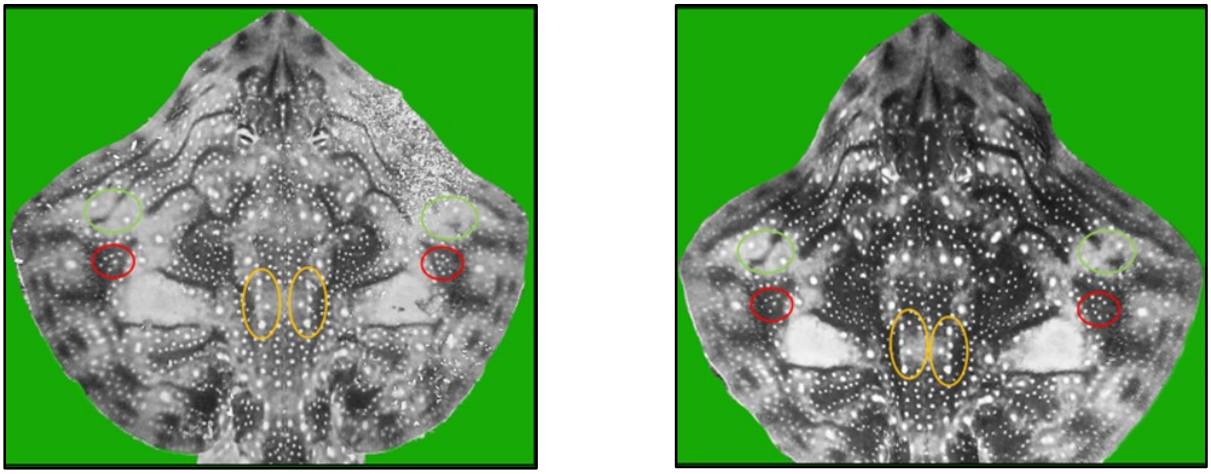

Figure 1: Two processed images of an undulate ray showing identical areas for comparison on the body (yellow) and wings (red).

In the example above, the two photographs of “Garay” were taken in 2013 about 1-week apart and compare the highlighted portions; the red circled areas show the same asymmetry of white dots on both images; the yellow ellipse highlights a similar asymmetrical feature on the body of the fish; and

the dark line marking in the green ellipse area is different on both sides of the fish. Any number of features can be selected in this way; these three features are just examples to show the technique.

The two photographs of "Blanc" below were taken in May 2017 and Sept 2013. In 2013 Blanc was a juvenile. Despite having grown in the three and a half intervening years and suffered some damage to his right wing, the pattern of wavy lines and dots remains the same and the identification process works in the same way. One of Blanc's 2013 photographs is used on the homepage of the *Undulate Ray Project* website.

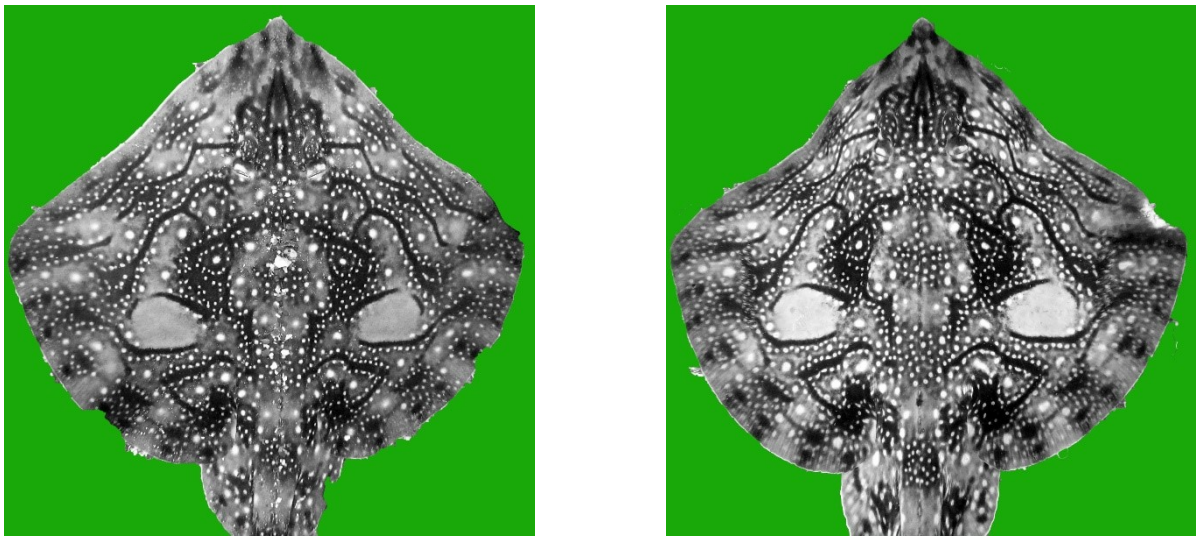

Figure 2: A male ray called Blanc photographed in September 2013 (left) and May 2017 (right).

Our assessment of matching photos is always done by two people to minimise the risk of "false positives" - assigning a match where one does not really exist. If any doubt exists at the end of the matching process, the rays will be considered as two different individuals. We believe chance of a "false positive" is extremely low and effectively zero.

False negatives

With over 500 individual undulate rays in the photo catalogue, the identification process is dependent on the computer system finding the correct potential matches. Where the dorsal pattern is partially covered or obscured by lighting reflections, matching images are not so clearly discriminated by the software and other images of the same fish may not have the highest matching coefficient. This situation worsens as the number of images in the database increases and there is an increasing possibility that matching images are then not identified in the 20 most likely matches. If the software does not identify two images of the same fish as potential matches, they are not evaluated further, and the associated sighting will become "false negative", i.e. recorded as not a match when there is another photo of the same fish in the database.

Efforts have been made to reduce this possibility by first considering images within local regions prior to across the entire project area, this significantly reduces the number of images being considered within the local region where a repeat sighting is most likely. If a matching image has been found within the local region analysis, it should also be found when processed with the full project photo catalogue. In only one case has a matching image, found in the local region data not

been rated in the twenty most likely matches for the full project catalogue. Although we cannot eliminate the possibility of false negatives they are considered to be relatively low.

Widening the net - citizen science input

The intriguing question and the initial background to the 2017 work, is "where do 'our' fish go when not on the site?" Combining the photo recognition with a citizen science program, we launched *The Undulate Ray Project* in 2017 to widen the monitoring of undulate rays along the south coast to try and track their location and movements. Aimed at divers, commercial fishermen and anglers the project asks them to send photographs of undulate rays from Devon, Dorset, Hampshire and the Isle of Wight. We acknowledge every contribution and each ray is checked against the others in the project. To get the best chance of matching photographs and to evaluate the performance of the software with a large database of photographs we check each fish twice, once within the area it was seen and again in the entire range of the project. The computer recognition software identifies potential matching photographs and the final analysis is done manually, as described in the section "Recognising individual undulate rays".

Although the success of the recognition process is greatly dependent on the suitability of the photograph, throughout the project the welfare of the rays has been the project's first concern. The project website (www.undulateray.uk) uses the opportunity to promote good handling practice and requests that anglers return the fish to the water as quickly as possible. We encourage divers not to disturb fish if they are partially buried, the ray will only swim off if disturbed.

The Outreach program is primarily based around the website (www.undulateray.uk) and associated Facebook page (The Undulate Ray Project), however, we also found it necessary to provide specific talks and presentations to gather additional support. After speaking at a number of gatherings of divers and anglers one dive club has (after checking with PADI) used our presentation as part of their 'Shark Aware' qualification and Wight Dolphins BSAC club have considered taking over the analysis of the undulate rays around the Isle of Wight.

Website and Facebook group

The initial website was launched in January 2017 at the Dorset Seasearch winter gathering and we were amazed and pleased to get nearly 2,500 visitors to the website within the first three days, as people shared links via Facebook. By December 2017 the website has been visited by over 25,000 people (75,000 hits) and the Facebook group has 245 members. During 2017 as we gained experience with the image recognition software, additional pages were included to provide guidance on taking the best photographs for recognition, and a page to provide feedback on the progress of the project.

The Great Eggcase Hunt

The Outreach program provided us the opportunity to promote the Great Eggcase Hunt, an existing project run by the Shark Trust. The location of nursery sites is of particular interest and the percentage of eggcases reported underwater is very low, therefore we have been encouraging divers to look out for them. Undulate rays are expected to lay pairs of eggs every few days, most likely in spring or summer and given the number and frequency of rays seen on the main site we

suspect there should be eggs in relatively close proximity but to date, they have not been found. Additional exploratory diving in the surrounding area is planned for the future.

Response

The response to the outreach program during 2017 has been hugely encouraging. We were encouraged by the number of organisations who offered their support, either with advice or helping promote the activity through their social media. These included BSAC, Dorset Coast Forum, Southern IFCA, the Marine Conservation Society, Weymouth Sea Life Centre, Seasearch and the Shark Trust. Additionally, both BSAC and PADI dive clubs have helped promote the activity and the angling community has provided a fantastic exposure through Facebook and social media contacts.

The idea appears to have captured peoples' imagination, especially with anglers and we have received over 700 photographs during 2017 from 88 different contributors. The photographs are processed, as described in the section "Pre-processing of photographs", and associated data are stored in a Microsoft Access™ database. After processing through the ray recognition software each sighting is assigned a unique sighting reference number and each ray is assigned a unique ray reference number. When a match occurs we contact the original contributors, not only to tell them 'their' fish has turned up again, but to ask them to choose a name. Any fish seen on more than one day continues to get a name, in alphabetical order, see later section on "**Error! Reference source not found.**". The use of names (many tongue-in-cheek) has been an enormous help in engaging with sections of the public and we plan to include an explanation of the names on the website at a future date.

Further outreach

In addition to the above, the project has received further publicity through photographs and video obtained by project member Matt Doggett. One of Matt's images was placed in the 2018 Annual British and Irish Underwater Photography Championships run by BSOUP which helped to further promote the project within the UK diving community (Plate 5). Matt also gained video footage of rays at the study site and of the DNA sampling process (see below). The video footage and still images have been provided to team member Samantha Hook for her own 'outreach' work and was due to be used in the BBC2 show Hugh's Wild West; unfortunately the number of episodes in the series was reduced and the story did not make the final cut although the BSA-JT funded Black Bream Project did feature in Episode 2!

We plan to produce our own project video in the near future and continue to promote the story to media outlets, including magazine articles.

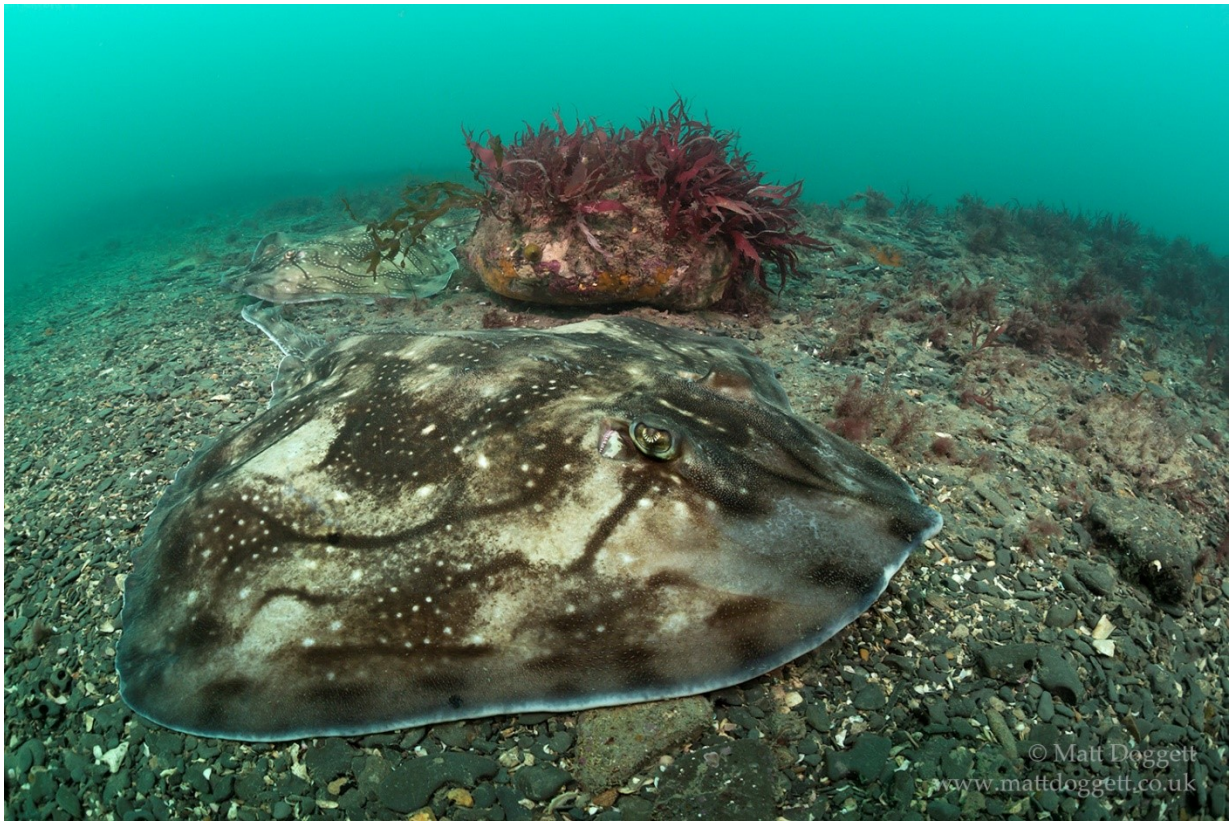

Plate 5: Matt's image of two undulate rays at Kimmeridge taken in August 2017 and Highly Commended in the BSOUP 'Splash-In' competition.

Genetic (DNA) sampling

The Undulate Ray Project is pleased to be assisting Samantha Hook from the University of Manchester by using swabs to collect DNA from undulate rays in their natural environment. Contact with Sam was made at the European Elasmobranch Association Conference in October 2016. Sam is also a BSAC diver and member of Manchester University SAC. Following discussions we modified our diving plans for summer 2017 to take advantage of this rare and sustainable opportunity to obtain DNA in a harmless way, rather than the traditional method of using fished animals.

The project at the University of Manchester is using genetic markers of undulate rays to determine the differences between populations from Morocco to the English Channel. This helps to understand the structure of existing known population(s) and assess the potential impacts of historical overfishing of the species. Concerns exist that individual populations may be isolated with limited migration resulting in a localised lack of genetic variation in some areas. Lack of genetic variation prevents a population from adapting to environmental changes; for example, populations may be more susceptible to diseases due to a lack of genetic variation thereby causing a species to become endangered or even go extinct. Analysis of the samples gathered will assist both the understanding of the genetic structure of the wider population and may even identify relationships between the fish known to *The Undulate Ray Project*.

Samples were collected from the rays at the Project's study site using a swab to collect mucus and skin cells from the dorsal surface (Plate 6 and Plate 7). When collecting DNA samples diving was

limited to two pairs of divers per day to avoid putting undue stress on rays. Initially it was thought the physical contact might cause the rays to swim away and that they could, in future, associate divers with a level of interference therefore making it more difficult to take the recognition photographs. In practice, the experience has been quite the opposite and most rays stay still and allow the diver to take several swabs. All swabs have successfully displayed high levels of mucus.

Overall, the team collected 56 DNA samples from 48 rays including some that had been seen on the site in 2013, 2014, 2015, 2016 and 2017. The repeat samples from individual rays will be used to confirm the photographic identification process. This work will continue over the next two years with some of the first scientific publications scheduled for 2018.

Further information on this project element is contained on the project webpage.

Plate 6: After this undulate ray has been recorded photographically, team member Samantha Hook takes a DNA swab from the dorsal surface, at the Kimmeridge study site.

Plate 7: The DNA sample bag and reference number are then photographed by Martin Openshaw for direct matching with the record of the ray's dorsal pattern. The ray, unphased, remains calm on the seabed.

Interim data analysis

Our efforts in 2017 coupled with the additional input from anglers and other divers have significantly increased the data available. At the time of writing there are 669 photographic records of 525 individual undulate rays in the catalogue, 59 of which have been seen on repeat occasions.

Although the overall data catalogue remains dominated by the sightings on the original Kimmeridge site (288 of the total 669 images) photographs have been received from as far afield as Torquay in the west to Littlehampton and Worthing in the east; the majority originate from Weymouth and Poole which have been the focus of our outreach activities.

Within our records we have four clusters of records from groups of enthusiastic divers and anglers who repeatedly visit the same sites; these are Chesil Cove, the original site at Kimmeridge, a sea area off Swanage and Boscombe Pier. Although rays have been recorded on repeat occasions in each of these areas in relatively close proximity we have no record of a ray making any significant movement along the coast. So far all repeat sightings of individual rays are from the same sites which suggests a high level of site-fidelity in undulate rays.

There are differences in the data from each area, but the size of each area, the duration of monitoring and the monitoring technique (diving versus angling) all differ and at this stage at least, are the major influence on the data.

	Chesil Cove	**Kimmeridge**	**Off Swanage**	**Boscombe Pier**	**Overall Project**
Data source	Predominantly diving	Diving	Predominantly angling	Angling	Angling and diving
Location type[1]	Shoreline	Inshore coastal waters	Inshore coastal waters	Shoreline	-
Monitoring period	1+ years	5+ years	1+ years	1+ years	
Sightings[2]	42	288	163	38	669
Individuals[3]	35	179	151	34	525
Individuals seen more than once[4]	5 (14.2%)	45 (25.1%)	6 (4.0%)	3 (8.8%)	59 (11.2%)
% return[5]	20%	60.9%	7.9%	11.8%	27.4%

Notes:

1. Location Type: - In the context of this project a "Shoreline" location is typically within 100 metres of the shoreline and approximately 5 metres deep. "Inshore coastal waters" are over 0.5 miles from the shoreline and typically 15-metres deep.
2. Sightings: - An individual ray photographed on one particular day. Rays seen more than once on the same day are considered as a single sighting. The same ray seen on two separate days is considered as two sightings.
3. Individuals: - The number of rays with photographs suitable for identification purposes.
4. Numbers in brackets represent the percentage of identified individuals seen on more than one day.
5. % return: - Repeat sightings (Repeat sightings = $\sum_{individual}$Repeats/Number$_{Individuals}$) expressed as a percentage of the individuals. Similar to return rate in a tagging program.

Most data originate from the Kimmeridge site as monitoring has been underway there since 2012; submission of images from third parties has occurred only since 2017 but does include a limited number of images taken in previous years. The repeat sightings from Kimmeridge (25.1%) have increased gradually over time as rays seen in previous years are seen again, sometimes up to 4 years later; the very high return rate (60.9%) reflects that some rays have been seen three, four or five times. The highest number of repeat days that an individual ray was seen over the five years of monitoring at Kimmeridge was five, across a three-year period. The diving takes place in very specific locations, limited by a diver's range; the fact that individual rays are rarely seen multiple times suggests that the rays are not resident at the specific locations but either have an extended home range or move in and out of the area. Santos Cabral[6] estimates that undulate ray home ranges can be between 0.3 and 1.3 km^2; extension of the present Kimmeridge study area might yet yield a higher percentage of repeat sightings.

The area "off Swanage" is a much greater area than the other sites, representing a 10 km stretch of coast from Durleston Head in the south to Poole Harbour Entrance in the north. Given the size of this area compared to the others, it is reasonable to assume the overall population of undulate rays might be far greater (thereby explaining the lower rate of repeat records) and continued effort will be required to gather more repeat sightings.

[6] Santos Cabral, S. dos (2014). *Raja* spp. spatial dynamics in the Arrábida Marine Park. *Masters Thesis*, Algarve University, Faculty of Sciences and Technology [Available online, DOI:10.13140/RG.2.1.3831.4486].

The rate of repeat sightings from Chesil Cove is similar to that from the first year of recording at Kimmeridge and can therefore be expected to increase in a similar manner if image submissions continue.

Recent published work on other UK ray species[7] used depth recording tags to identify "*previously unknown diel inshore–offshore migrations that likely result in the animals having a wider dispersal and larger area of occupancy than might otherwise have been considered over short time scales*." The authors' analysis of depth profiles concluded that the rays rested in deeper water during the day and foraged in shallower water at night. Our observations are consistent with this behaviour pattern: -

- The rays on the Kimmeridge site are always found resting on the seabed and have been observed to remain in the same place for several hours.
- This behaviour is consistent with other diving records where rays are generally reported to be lying on the seabed on off shore sites during the day but also seen being active in shallower water during night dives.
- Although not always the case, angling reports are generally from angling boats at sites away from the shoreline during the day and shoreline angling at night.

Interim conclusions and on-going work

A methodology has been developed to identify individual undulate rays from photographs of the pattern on their upper dorsal surface. This technique has been used as a non-intrusive alternative to conventional tagging to monitor undulate rays along the south coast of the UK. The data support the high levels of site fidelity reported with undulate rays and further suggest that rays may remain local to individual areas over successive years, even though they only visit a specific location on a periodic basis.

The frequency of repeat sightings at the original Kimmeridge site, approximately one in four, suggests that the overall ray population visiting the site is not large. An initial statistical evaluation using a simple Lincoln Index based on annual repeat sightings put the overall population to be in the range 300 – 500 rays; however, this analysis needs to repeated with the most recent data. None of the 179 individuals identified from Kimmeridge have been recorded elsewhere. Although still requiring further analysis, this is an initial indicator that the rays may not travel too far from the site. These observations concur with telemetry tagging work in the Arrábida Marine Park in Portugal[6] indicating that undulate ray populations exhibit seasonal and daily movements but have preferred habitats. Humphries et al. provided several hypotheses for possible drivers of the daily migrations but could not single out a clear motivation for the animals' behaviour. One potential motivator that appears not to have been considered in detail is the energy benefits derived from resting in areas not subject to high currents or tidal movements. The undulate rays are caught at night in inshore areas; observations from participants in the undulate ray project suggest they are actively foraging during this time. Diver observations from the Undulate Ray Project made during the day, record rays in deeper areas, often (but not always) close to reefs, ledges or outcrops that may provide shelter

[7] Humphries, N.E., Simpson, S.J., Sims, D.W. (2017). Diel vertical migration and central place foraging in benthic predators. Marine Ecology Progress Series, 582: 163-180 [DOI: 10.3354/meps12324].

from strong currents and are less susceptible to wave swell. Our data might help to clarify this further.

The DNA analysis will provide further key data to support our understanding of undulate ray populations along the Dorset coast.

Data are still being collected and will build to provide further evidence of the undulate ray behaviour. In particular anecdotal comments from divers and anglers could become an important source of information supplementing the data collection.

The data are still being analysed, the DNA results need to be finished and people continue to send in their photographs adding to the dataset. In 2018 we plan to focus on areas close to the original study site, supplement the data with further observations that will add to the understanding of undulate rays' ecology and behaviour.

Final thoughts

The project has (and continues to) demonstrate how carefully planned and executed dive projects, coupled with thoughtful use of social media and other outreach techniques, can be used to engage with people beyond the realm of diving and promote interest in UK marine life and scientific research. Interest in the project from divers, anglers, scientists and other community groups has been outstanding - at times almost overwhelming. We believe our approach to this project has been very effective in promoting not only British diving but 'local diving' and 'diving with a purpose'.

Tables

Talks and presentations

Date	Organisation
March 2015	Porcupine Marine Natural History Society
October 2016	European Elasmobranch Association Conference
January 2017	Dorset Seasearch Winter Meeting
January 2017	Southern Inshore Fisheries and Conservation Agency Meeting
February 2017	BSAC 807 Wight Dolphins Meeting
March 2017	Porcupine Marine Natural History Society
April 2017	Flippas 'n' Fins PADI Dive Club
May 2017	Southern IFCA Technical Advisory Committee
May 2017	Poole Small Boat Angling Association
June 2017	National Oceanographic Society Marine Life Talk
June 2017	Weymouth Angling Society/Weymouth & Portland SAC
October 2017	Community Science Conference, National Aquarium, Plymouth
November 2017	Dorset Coast Forum

2017 Diving on the Kimmeridge site

Dive Date	Rays seen[8]	Individuals Identified	Comment
02 April 2017			Visibility less than 1-metre
11 April 2017	1		Bream Monitoring
20 April 2017	1		Bream Monitoring
23 April 2017	1		Bream Monitoring
23 May 2017	1	1	Bream Monitoring
31 May 2017	3	3	Bream Monitoring/Ray Spotting
14 June 2017	13	10	Bream Monitoring/Ray Spotting
19 June 2017	8	8	Bream Monitoring/Ray Spotting
04 July 2017	15	11	Bream Monitoring/Ray Spotting
08 July 2017	5	4	Bream Monitoring/Ray Spotting
08 August 2017	17	14	Ray Spotting/DNA Sampling
13 August 2017	16	13	Ray Spotting/DNA Sampling
14 August 2017	14	14	Ray Spotting/DNA Sampling
26 August 2017	23	18	Ray Spotting/DNA Sampling
27 August 2017	13	12	Ray Spotting/DNA Sampling
02 September 2017	16	16	Ray Spotting/DNA Sampling
08 October 2017	2	2	Ray Spotting/DNA Sampling

[8] Rays seen includes species other than undulates, specifically thornback, spotted and small-eyed

Ray Names

Al	Alex	Andrayea
Billy	Blanc	Brayanna
Charles	Crayg	Charaybdis
Dierdray	Desiray	Dr Dray
Elanna	Erayc	Elfrayda
Fraydo	Freya	Frankie
Garay	Grayce	Gale
Harray	Higgy	Henray
Irayna	Irayea	Igor
Juno	J	Jerray
Katiyanna	Katie	Kerray
Lorayne	Larray	
Morayarty	Martine	
Nead	Noray	
Orayana	Olly	
Persephone	Polly	
Queray	Que	
Rey	Raymond	
Stephanie	Samantha	
Torvill	Teraysa	
Uray	Ula	
Vaughan	Victoraya	
Wanda	Wendy	
X	Xerrys	
Yveray	Yikes	
Zacharay		