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Measuring snapper from Video Footage: A Forensic Perspective

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Table of Contents

1 Background

In 1990 the Auditor General and the Parliamentary Commissioner for the Environment (PCE) jointly reported that the NZ quota management system (QMS) was '*a system struggling to provide the necessary information for management decisions which can control fishing at sustainable levels and ensure the sustainability of the fishery resource* (Cameron & Hughes 1990). One of the problems highlighted was unreported dumping. Nine years later the PCE noted that little had changed, and that '*effective monitoring and compliance are virtually impossible for New Zealand's fisheries resources*' (Williams 1999).

The PCE reports highlight the underlying paradox of the NZ QMS. To function correctly the system needs the fishermen to supply the Ministry with accurate catch data. The statement that *effective monitoring and compliance are virtually impossible* reflects this paradox. The management system provides perverse incentives to dump and highgrade at sea (Torkington 2015), and waterborne enforcement is seldom possible. The only intervention that has proven effective is placement of a government observer onboard each vessel, and observer coverage is costly.

However, advances in CCTV technology have made it possible to reliably capture footage of events on board vessels, and also embed details of time and location in this footage. This raises the prospect of using electronic monitoring (EM) as a cheaper alternative to universal placement of human observers.

EM is already being trialled, implemented or used in a number of foreign fisheries to satisfy various objectives. The first trial of EM in NZ waters was aimed at studying the interaction of set netting vessels with marine mammals, especially Hector's Dolphins. A second trial was conducted in 2014 with the objective of estimating the weights of snapper being discarded in the SNA1 fishery in the north east of the North Island. This second trial was the spur to the work reported here.

Snapper have a minimum legal size. For a commercial fisherman it is an offence to retain a snapper measuring less than 25 cm. But under the NZ quota management system it is an offence to dump fish of legal size. Any snapper measuring > 25 cm is required to be landed. Dumping snapper longer than the minimum legal size is a serious offence.
If EM becomes mandatory it is inevitable that MPI will wish to use this technology to measure the discarded snapper that are visible in the footage obtained. Fisheries management staff will wish to assess the degree of quota induced discarding in the fishery, and track the success or otherwise of any changes in policy settings designed to minimise this. Compliance staff will wish to use the footage as evidence of high-grading and dumping. MPI and Seafood Industry Council economists will doubtless be interested in assessment of the amount of wastage in the fishery and in estimating economic yields foregone. For all these purposes it will be necessary to measure or estimate fish lengths.

The purpose of the work described in this document is to assess just how accurately fish length can be measured using the type of technology and installation employed in the 2014 SNA1 EM trial, and to consider some of the issues which would arise if this type of footage were to be used in the courtroom as evidence of illegal dumping.

2 The 2014 SNA1 Trial

During the course of 2014 ten vessels in the SNA1 fishery were fitted with video camera and recording systems. The cameras were installed as part of a trial looking at the estimation of snapper discard weights by electronic monitoring. Five of the vessels were fitted with systems supplied by Archipelago Marine Research Ltd, and the other five with systems supplied by Trident Systems Ltd. Both companies were invited to supply a system for evaluation in the Fisheries Forensics Laboratory, and we are grateful to Archipelago for doing so.

The trial was conducted under a Memorandum of Understanding between MPI and the SNA1 Commercial Group. The MOU specified *inter alia* that

- At least two cameras were to be deployed on each vessel, giving both a general overview and a detailed view of discard points.

- Fish were to be discarded from no more than two points, both within the unobstructed view of a camera.

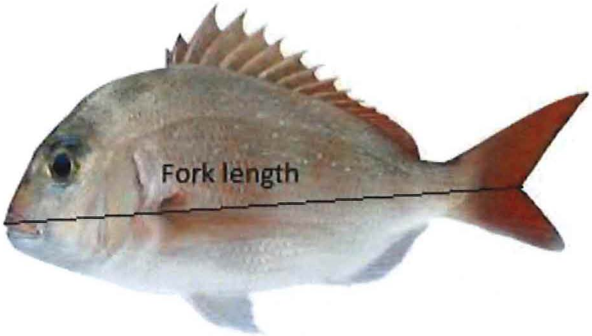
- Snapper destined for discarding were to be batched to allow quantification at the tow level. In practice this meant that the snapper to be discarded were placed in fish bins and discarded by the bin, rather than being flicked over the side of the vessel individually during sorting.

The Archipelago system collected one image from each camera every 10 seconds whilst the host vessel was outside the Port Area, as well as a good deal of other data which is not relevant to the issue of measurement. The Vivotek Fixed Dome network cameras used are capable of recording frames of 128 KB each but a lower resolution can be selected when the camera is set up. Because data storage capacity is limited there is inevitably a trade-off between image quality and frame rate.

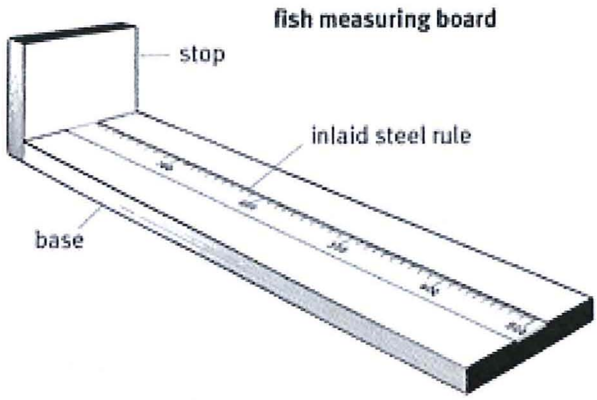
The installation and operation of the Archipelago systems are fully described in Archipelago's report on the trial (Pria *et al* 2014). A similar report from Trident Systems Ltd was being drafted at the time of writing. Because we have not had access to a Trident system we are unable to comment on its performance. However, both systems are designed to provide a distant oblique view of the fish being sorted and discarded from the trawl deck, and this raises a number of issues which will inevitably be common to both.

2.1 MEASURING SNAPPER VISUALLY

The legal measurement of a snapper is the fork length – that is to say the distance from the snout to the fork in the tail.



The traditional method of measuring a snapper is to use a fish measuring board. The person making the measurement has the fish under their control. The fish can be positioned correctly on the board, the tail can be spread manually so that the fork is visible, and the ruler can be read from directly above to avoid parallax errors. The measuring board is also a flat surface.



Measuring fish captured in photographic images is a different proposition altogether, and in the video footage available from the deck of the trawlers involved in the SNA1 trial:

(i) The tails of most snapper are not nicely spread;

(ii) Many fish from each tow are partially obscured by other fish lying on top of them;

(iii) The fish are oriented haphazardly but not randomly toward the camera;

(iv) The fish are not lying on a ruler or grid; and

(v) Some fish are lying on a very uneven surface.

A typical view might show snapper being binned prior to discard. Whilst being handled each fish is partially obscured by the handler: it will have been picked up by either the head or the tail, so one end or the other will be hidden in a gloved hand. Once binned the fish will be lying on a bed of other fish. This is not a flat surface, and some degree of lateral flexion is likely. Furthermore, unless the bin is completely filled the oblique nature of the camera views results in a part of many fish being obscured by the side of the bin facing the camera.

In the image above the whole of only one fish is visible, but there are partial views of at least seven more. The uppermost fish is clearly visible, but this fish is clearly not in a natural pose. The body of the fish appears to be conforming to the lumpy surface beneath, and the tail is not in line with the longitudinal axis of the body.

From a compliance perspective lateral flexion is unimportant since the bias is in the right direction. Any flexion will result in the length of the fish appearing shorter than it really is, and in a prosecution for dumping this bias will favour the defence. However, for the purposes of Fisheries Management and Science measurement of fish lying on an uneven surface will add an unwelcome source of systematic error.

However, I think this image presents the general case – we will be unable to measure the fork length of most fish in most images, and when we do make a measurement of fork length it will often be biased downward simply because of the surfaces on which the fish typically rest.

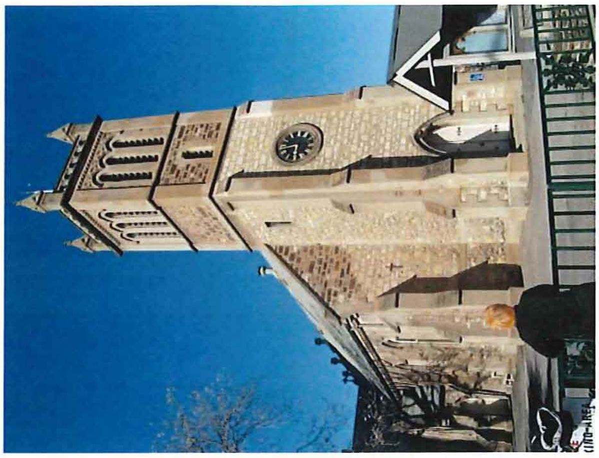
In this situation we will inevitably have to to use proxy measures for fork length, and these are discussed in a later section.

2.2 CORRECTING THE IMAGES

Excepting under the most carefully controlled conditions photographic images usually have some degree of perspective distortion. Rectification is required before use for measuring purposes.

> *Perspective distortion is a warping or transformation of an object and its surrounding area that differs significantly from what the object would look like with a normal focal length, due to the relative scale of nearby and distant features.*

We are all take holiday snaps and are familiar with the concept.



I've turned one of mine on its side to highlight this effect. The sides of the bell tower appear to be converging toward the left of the image, while the gaps between the fence railings get progressively narrower toward the top right.
There are various methods of correcting for perspective distortion mathematically. There is a large literature on the topic, with a useful though slightly dated discussion in D'Ayayla & Smars (2003). This reference deals exclusively with simple non-stereoscopic images, which is the type we are obtaining from the EM cameras in the SNA1 trial.

In our images the fish are usually lying on the deck or in a bin. There are always several rectangular objects (bins, dolavs or hatch covers) in each frame, and these rectangles are in approximately the same plane as the fish. If we know the real life dimensions of one of these rectangles we can also use it as a scale, and the affine transformation that will convert the image of the rectangle back into a rectangular shape will also correct the apparent dimensions of any fish that happens to lie in the same plane. This works regardless of the fact that the image is strongly oblique.

The photo of the colonnade frontage below shows the effect of an affine transformation on an oblique image.

The mathematics involved are discussed (in a fishing context) in Chang *et al* (2009).

However, there is merit in **not** transforming the underlying image, but instead applying the transformation only to the measurements made. In the photo below the piece of brown cardboard is being used for reference. The image of both the snapper and the brown cardboard rectangle remain unchanged. The affine transformation that would be required to correct the reference rectangle is being used to compute the length of the fish. The same method can be used to calculate the dimensions of anything lying in the same plane as the projected grid.

All the work is being done by the software programme "Uphotomeasure", which is based on algorithms developed by Dr John Lane of NASA. Following the *Columbia* space shuttle disaster NASA wanted to review all of the available footage. The investigators needed a new method for analysing still video images to accurately determine the size of the material that fell from the shuttle during the launch. John was a scientist at the Kennedy Space Centre, and he devised a software programme to calculate the unknown dimension of the material in the images. Development continued after the investigation was completed, and eventually the algorithms and the programme were made available for commercial licensing. There are more details and some demonstration videos available at www.uphotomeasure.com.

This approach is very attractive from a forensic perspective. Measurements may be required in several planes, and provided suitable reference rectangles are available all can be made on the same image. Furthermore, the general public are generally suspicious of "trick" photography and any manipulation of images is fertile ground for defence counsel to exploit. Making the measurements on an untransformed image should be much easier to defend.

2.3 PROXY MEASURES FOR SNAPPER

A proxy variable is defined as:

a variable that is used to stand in for an unobservable quantity of interest. Although a proxy variable is not a direct measure of the desired quantity, a good proxy variable is strongly related to it.

In short, when you can't measure what you need you measure what you can, and you use these measurements to make a prediction.

We can't possibly measure the height of the female in the photo directly. Nothing we can do to the photograph mathematically will change her posture. But we have a clear view of her (L) lower leg, so we can get a good idea of the length of her (L) tibia. We know intuitively that taller people tend to have longer tibias, and that if we measure tibias on enough volunteers of known height we can work out a predictive formula. Once we have the formula we can use tibia length as a proxy measure and estimate her height from this. We will never know her height exactly but we may get close, and if we have enough volunteers we should be able to estimate some range within which her true height must be.

All this work has been done already for humans of course. Forensic pathologists have standard equations to determine the original height of a human victim from skeletal remains, and these usually rely on extrapolation from the length of bones like the tibia, the radius or the first metatarsal (eg, see Pelin & Duyar 2003).

Most of our snapper will be analogous to the female in the photo. We can't measure their length directly, either because we can't see the whole fish, because the body is flexed, or because the tail is not spread. We will have to employ proxy measures.

This is a common practice in fisheries work, especially when fish lengths are being estimated from underwater cinematography. Most fish swim by continuous lateral flexion, and even with a stereoscopic system accurate measurement of something like a ling is almost impossible because the body is never stretched out in a single plane. Karpov et al (2009) recommend the routine use of vertical morphometric proxy measures in place of direct measurement of length from underwater videos to solve this problem. We have a long history in Compliance of using proxy measures for enforcement purposes – meat weight as a proxy for shell length in shucked paua being an obvious example. But although there are various proxy measures already in the literature for various species we don't know of any work published on snapper. And in the absence of any prior work it may not be possible to seize any footage as evidence of dumping.

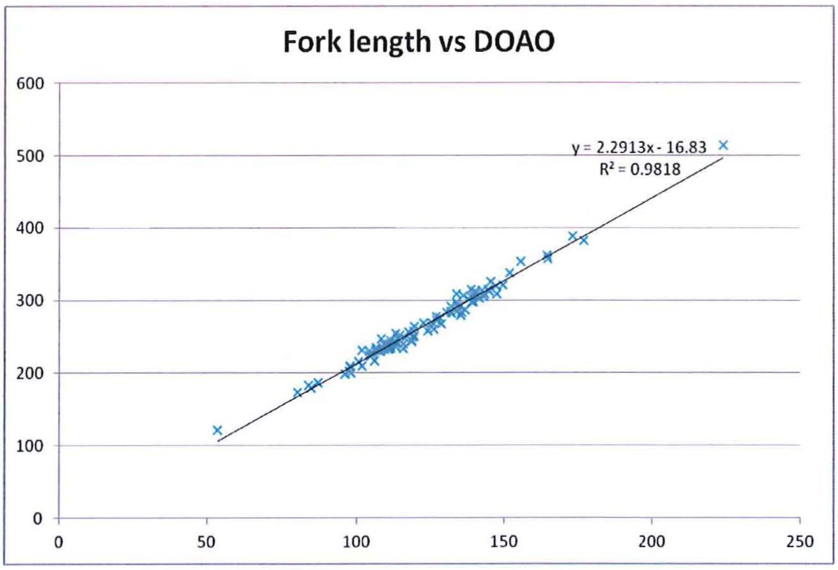
This point arose during Operation Mini, in which we intended using the distance between the dorsal fin and anal fin origins as a proxy for length in hoki. The fish of interest had been dressed, so measurement of standard length was not practicable. However, there was concerned that the use of this proxy measure would constitute "novel science" and that there was no "evidential model" in place at the time the suspect fish were seized. As a result the operation was abandoned. It seems that for legal reasons we are unable to develop proxy measures as we need them for use in casework: instead we have to do the work in advance and prove that the measure is useful prior to seizing any fish or footage as evidence.

With the Operation Mini precedent in mind, we obtained 103 snapper covering a range of sizes from the Hauraki Gulf. The fish were collected by an observer embarked on a commercial vessel and ranged in length from 12.1 to 51.4 cm. We measured the fork length of each fish along with 12 potential proxy measures. Fork length and total length were measured using a measuring board, and the remaining measurements were made with vernier calipers whilst the fish was lying on its side on a flat surface.

The measurements made were:

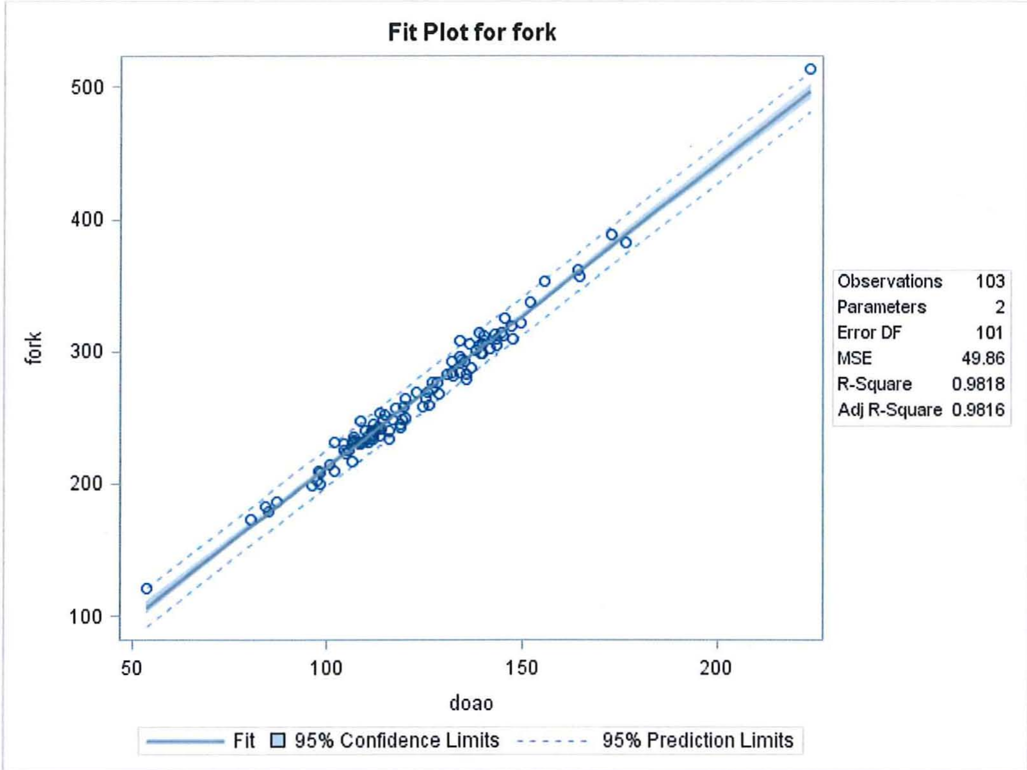
Total length – the length from the snout to the furthest tip of the tail
Snout to pelvic origin –the distance from the snout to the origin of the pelvic fin
Snout to pectoral origin
Snout to anal fin origin
Snout to dorsal fin origin
Snout to mid orbit – the distance from the snout top the centre of the eye
Snout to opercular tooth – snapper have a tooth-like projection on the distal edge of the operculum, and the measurement is made to the tip of this tooth
Mid orbit to opercular tooth
Lower jaw
Pelvic fin length
Pectoral fin length
Dorsal origin to anal origin (DOAO)
Depth at mid orbit
Depth at pelvic origin = pelvic fin origin to dorsal fin origin
Depth at anal fin

All of the measurements made seemed to be linearly proportional to fork length, though the strength of the relationship differs. A scatterplot showing the relationship between fork length and the dorsal origin to anal origin measure is shown below.



From the graph above it is clear that the relationship, although tight, is not perfect. If we look at the fish with a DOAO measurement of around 100 mm the fork lengths seem to vary between 200 and

230 mm. We can go further than simply eyeballing the graph and formally calculate the 95% prediction interval for any given DOAO measurement. The prediction interval is the range within which the fork length of the next fish of the same DOAO measurement would be expected to lie, and for a fish of 100mm DOAO this range is 199 to 228 mm fork length. The scatterplot below shows the same data with the 95% prediction limits included as the broken lines.



For compliance purposes we are interested in the discarding of fish which are unequivocally larger than the minimum legal size of 25 cm fork length. We are therefore interested only in fish where the lower bound of the 95% prediction limit is larger than 25 cm.

Table 1 below shows the smallest value of each of the proxy measures at which the lower bound of the 95% prediction limit will be > 25 cm, and the average fork length of fish of this size. So we can be certain that any snapper with a DOAO measurement of 127 mm or more will be of legal size, and on average a fish with this measurement will have a fork length of 27.4 cm. In practice this means that for a fish of (say) 26 cm fork length it will not usually be possible to say that it is of legal size purely on the basis of a DOAO measurement.

For fisheries management purposes the requirement is for an unbiased estimator of length and all of the proxy measures in Table 1 will provide this. For compliance work we want a proxy measure which minimizes the number of fish left in legal limbo, where we can't be certain whether they are of legal size or not. It is clear from Table 1 that some proxy measures are better than others in this regard. We should use the best proxy measure that we can for each fish that we want to measure, but we will inevitably be forced to use the features we can actually see in the footage received, and these features will vary from fish to fish. Remember *when you can't measure what you need you measure what you can*.

Table 1: Cut off value for proxy measures and average fork length at that size

Proxy Measure	Cut-off Value (mm)	Average Fork Length at Cut-off Value (mm)
Total length	321	271.6
Snout to pelvic origin	89.0	274.9
Snout to pectoral origin	82.3	275.3
Snout to anal fin	156.6	275.8
Snout to dorsal fin	109.1	278.7
Snout to mid orbit	40.7	280.4
Snout to opercular tooth	77.3	274.7
Mid orbit to opercular tooth	44.4	276.8
Lower jaw	28.1	282.7
Pelvic fin length	55.9	288.8
Pectoral fin length	93.4	285.8
Dorsal origin to anal origin	127.0	274.2
Depth at mid orbit	77.8	286.5
Depth at pelvic fin	107.0	281.3
Depth at anal fin	90.8	284.7

It is clear from Table 1 that unless we can see the fork length of a fish directly in a photo, determining whether or not any snapper of length 25 to 28 cm is or is not of legal size will be very challenging. This has nothing to do with quality of the imagery or the camera angle: it simply reflects the uncertainty inherent in the use of whatever proxy measure we choose to use.
Measuring from images introduces further uncertainty, and the effect is additive.

2.4 MEASURING FROM IMAGES 1: IMAGE QUALITY

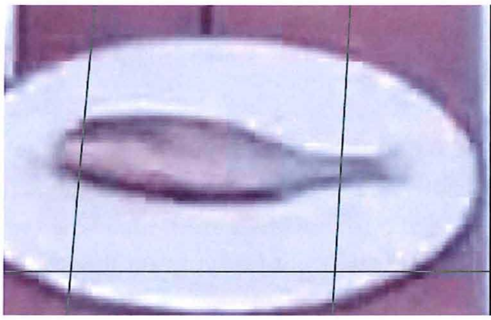
The pixilated nature of a digital image sets an absolute limit on the accuracy that can be achieved when measuring items in the image.

Our laboratory digital SLR (an Olympus E620) typically produces images of 4032 x 3024 pixels which are about 5 MB in size. If this camera is used to photograph the end wall of the laboratory, which is 4 m wide, and the wall completely fills the frame, then each pixel is 4000/4032 or approximately 1 mm wide in real life. If a fish were mounted on this wall we could measure it's length (or some proxy thereof) with tolerable accuracy from such an image, and it should be quite possible to make measurements to +/- 2mm provided there was a high contrast between the colours of the fish and the background.

The same scene photographed with a resolution of 800 x 600 pixels will have approximately one-fifth of the resolution, which is to say that each pixel will be about 5 mm across in real life.

Both the Archipelago and Trident camera installations used in the SNA1 EM trial are producing distant oblique images with wide angled lenses, and the Archipelago system is recording images of 1280 x 800 pixels per frame on the highest resolution setting. The practical effect on measurement accuracy will vary from vessel to vessel. However, in our laboratory setup the Archipelago Vivotek camera is mounted 8m from the snapper being measured with a 4.6 m field of view at this distance. At this setting (which we believe would mimic the situation on a 16 to 20 m trawler with the camera mounted atop the wheelhouse) each pixel is 3 mm wide, so we believe that in the very best circumstances measurements made from the images will be +/- 6 mm. This adds a major source of uncertainty for the smaller proxy measures listed in Table X. An uncertainty of +/- 6mm in the measured length of the lower jaw, for example, translates to a difference of +/- 5 cm in the fork length of the snapper being measured.

The purveyors of Uphotomeasure recommend a minimum of 4 megapixel images for subjects > 6 m from the lens. The distances involved on the vessels will often exceed this. At the highest resolution setting the cameras used in the Archipelago installations are delivering 1 megapixel images. In consequence at 8 m range the snapper looks like the image on the left when enlarged. The difficulties of making proxy measurements on an image of this quality are self-evident.



The second photo is an image of the same fish captured by the laboratory Olympus 12 megapixel camera through a telephoto lens.

Because storage space is limited video photography inevitably involves trading off resolution against frame rate. Both are important. However, if we wish to measure fish accurately in distant images then high resolution images are essential. The only alternative is to bring the fish closer to the camera.

Additionally, environmental factors such as lighting and the presence of contaminants i.e., water, salt spray, oil, etc., on the lenses would further adversely impact on the quality of the imagery. The cameras are only equipped with a single CMOS sensor, therefore, the reliability of the color rendition is uncertain.

2.5 MEASURING FROM IMAGES 2: THE EFFECT OF "OUT OF PLANE" MEASUREMENT

As noted above, the methodology employed in the Uphotomeasure programme requires the reference rectangle to be in the same plane as the fish being measured. In practice this will seldom be the case. The thickness of a fish typically tapers from the head to the tail, as shown in the image of a tropical grouper below.

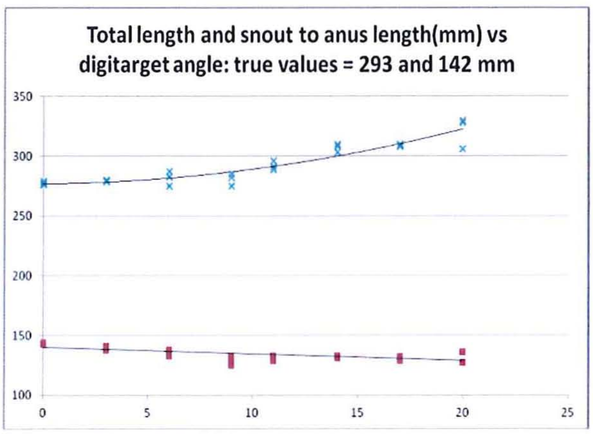
This gives rise to two geometrical issues.

Firstly, the legal measurement of the fish (as determined with the use of a measuring board) is not the distance from the snout to the fork in the tail, but the distance from the right angle of the measuring board to the fork. In reality we have a right angle triangle: the snout will be butted against the upright limb of the measuring board. If we measure the actual length of the fish from snout to fork with calipers it will be slightly longer than the reading on the measuring board since the calipers are measuring the hypoteneuse rather than the adjacent side. This issue is trivial with a streamlined fish like a snapper: if a 30 cm long snapper is 7 cm thick when lying on the measuring board the caliper measurement will be 30.2 cm. The measurements we are making from our images are analogous to the caliper measurement, not the measuring board.

The second issue is more serious. Even if the reference rectangle and the fish are lying on the same flat surface the dimension being measured will seldom be in exactly the same plane as the rectangle. The fork length and total length measures will typically be inclined at 5 to 7 degrees from the plane on which the fish is lying. But often the reference rectangle and the fish will not be lying on the same surface and subtle differences in angle may not be obvious in the footage.

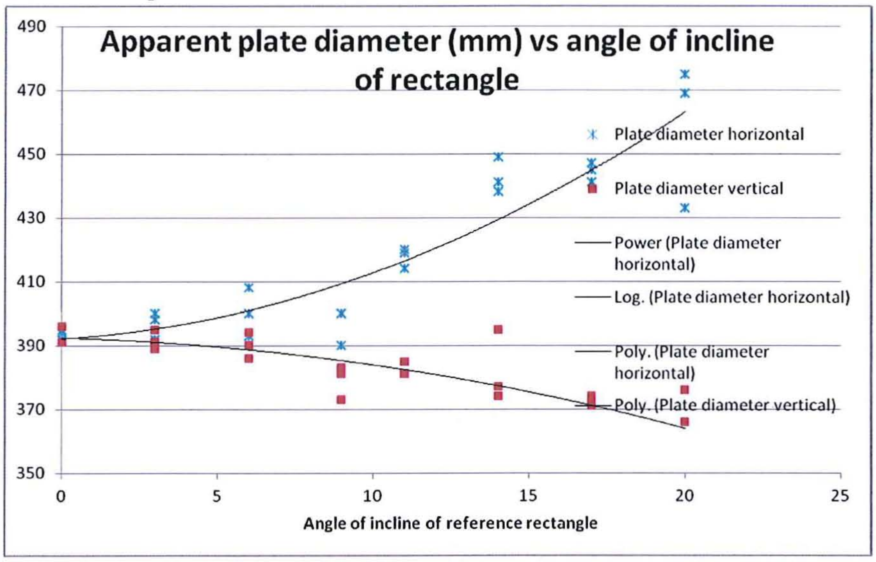
We conducted an experiment in which the fish in the image below remained stationary and the reference rectangle was gradually angled out of the plane of the table by progressively elevating the left hand side. The angle of decline of the camera was 30 degrees, and each measurement was made in triplicate.

The effect of elevating one side of the reference rectangle on the measurements of (i) snout to anal fin length; and (ii) total length are shown in the graph below.



The snout to anal fin measurement is made in the same plane as the reference rectangle initially, and the caliper and Uphotomeasure measurements are in close agreement at 142 and 143.5 mm respectively. The apparent snout to anal fin distance becomes progressively shorter as the reference rectangle becomes more steeply angled. The total length measurement is initially too short at 278 mm. The true value is 293 mm. However, as the reference rectangle is angled upwards the apparent length of the fish increases. Both results are what one would expect from the relative geometry. Measurements made parallel to the long axis of the reference rectangle will appear longer as the angle of the rectangle increases. Measurements made parallel to the short axis of the rectangle will appear progressively shorter.

This effect is shown very clearly in the graph below. This shows the apparent diameter of the circular plate on which the fish is lying. The "horizontal" measurement is parallel to the long axis of the rectangle, and the "vertical" measurement is perpendicular to this. The horizontal and vertical measurements begin in very close agreement and progressively diverge as the reference rectangle is tilted out of plane.



The possibility that a fish length could be overestimated is of concern for prosecution purposes. If the angle of divergence between the fish and the reference rectangle could be determined a mathematical correction could be applied. However, reference to the image of binned snapper below shows that this is not a realistic possibility.

In this image the obvious reference rectangle is the top of the bin. All of the fish are lying below this plane, which is not a problem in itself since this will just result in a slight underestimation of length. We have a clear view of the pectoral fin of fish A; the snout and the pectoral fin origin of fish B, and enough of Fish C to make a direct measurement of fork length. But it is very difficult to visually assess whether any of these measurement lines are parallel to the plane of the top of the bin.

If we need to employ three dimensional geometry we need to begin with a stereoscopic image. The Archipelago and Trident systems are not delivering stereoscopic imagery so the best we can do is apply an allowance sufficient to cater for the worst case scenario.

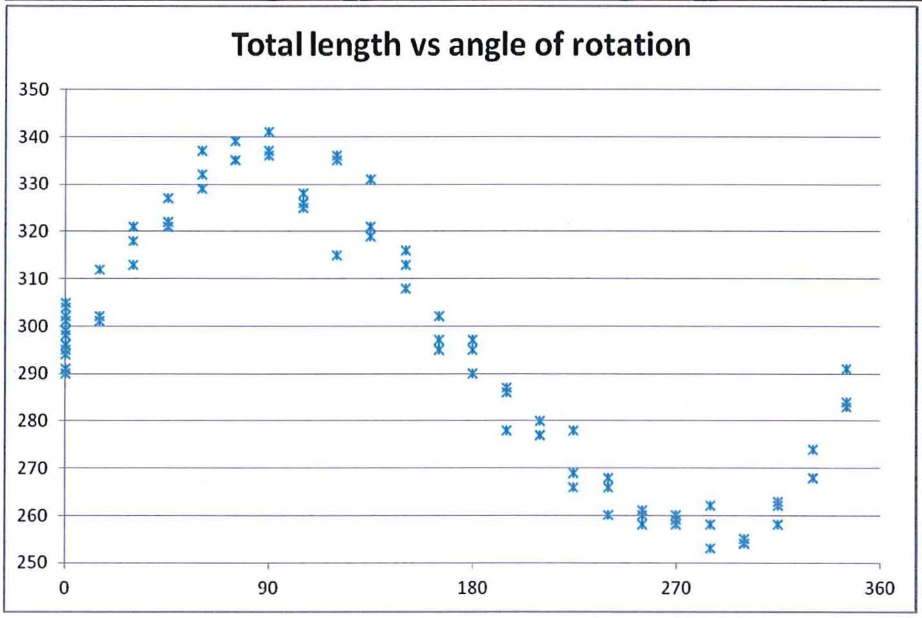
If we assume that a divergence from the plane of the reference rectangle of 15 degrees or greater will be obvious to whoever is making the measurements, and that divergent measurements will be excluded, then an allowance of 12% would suffice. In practice, this means that the cut-off values in Table X would need to be increased by this amount. So for fish B, where we are relying on the snout to pectoral fin measurement the cut-off measurement would be 82.3 mm x 1.12 = 92.2 m, which translates to a fork length of about 306 mm. A further allowance needs to be made for the resolution of the image, but this will vary depending on the camera used and the distance from the lens to the subject.

2.6 MEASURING FROM IMAGES 3: ROTATION

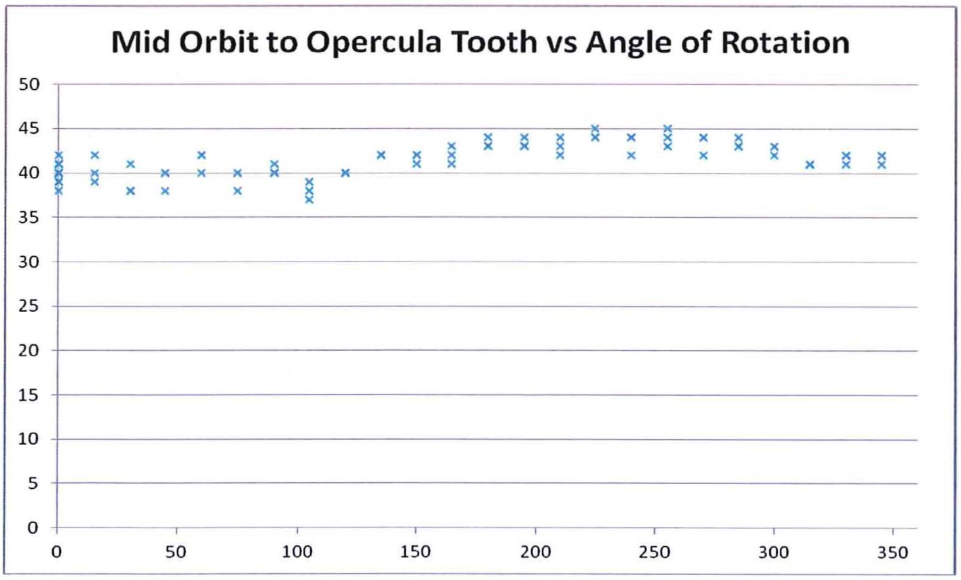
As noted above, a snapper tapers in thickness from head to tail. In consequence the long axis of the fish is always inclined at an angle of 5 to 7 degrees with respect to the surface on which the fish is lying. When using the reference rectangle/affine transformation method of measurement this inclination means that the apparent length of the fish will change as it is rotated with respect to the reference rectangle.

The effect will be more pronounced for some proxy measures than others, as some are always in roughly the same plane as the resting surface and others are not. The oblique nature of the footage also contributes to the effect of rotation, as some of the anatomical landmarks required are more easily discerned at some angles than others.

The graphs below shows the effect on the apparent length of several proxy measures when a snapper is rotated through 360 degrees. Measurements were made every fifteen degrees. The angle of declination of the camera is 30 degrees.



As expected, the apparent total length of the fish follows a sinusoidal pattern. The true value for this fish as determined with a measuring board is 301 mm. The wave amplitude is diminished for the mid orbit to opercular tooth proxy because the plane of the measurement diverges less from the plane of the surface.



2.7 FROM MEASUREMENT TO EVIDENCE

For any of the measurements to be useful as evidence we need to be able to:

(i) Prove the chain of evidence of the imagery from the vessel to the laboratory, and from the video file to the still snapshots of single frames that will be used in the measuring;

(ii) Demonstrate the reliability of the embedded data on position, time and date;

(iii) Explain the method of measurement and defend the various assumptions made in making it;

(iv) Explain and defend all the proxy measures used; and

(v) Provide a great deal more data on the reliability of the method in situations that more closely approximate the real world.

The first point is virgin territory. We have had access only to a system dismounted from a vessel, not to a system working in situ and connected to the onboard sensors etc on a vessel. It is inevitable that in the real world the footage will pass through several hands and from one storage medium to another on it's journey to a compliance officer. If any decision is made to implement EM more widely MPI need to consult a computer forensics specialist on ways in which the chain of evidence can be preserved.

Video recording systems such as those used as part of a CCTV (Closed Circuit TV) system of DVR (Digital Video Recorder) system often use propriatory video file encoding to make the video footage unviewable without using a special viewer. Additionally, that encoding often makes it difficult to extract the video footage in its orginial format. The result is that the special viewing softaware required often only permits video files to be output in a lesser quality, but more commonly accessible and viewable format. This raises a couple of issues: firstly, the process of extracting the video footage has altered the video format as it is no longer in its orginial format as written to the storage hard disk. Secondly, an issue arise from the propriety nature of the footage and it being extracted to another format is that often the extracted video footage is of a lesser quality than the orginial video footage. Both of these issues could lead to issues around proving that the alterations have not materially affected the evidence, which could be difficult if the original footage is not captured and retained and that the extracted video footage has lost detail that would be useful in determining the size of the fish captured by the EM.

Digital evidence is easily altered whether it be the metadata embedded in the image file i.e. when the image was taken or to the image file itself by altering the content what the picture looks like. Implementing 'write-blocking' technology can maintain the integrity of the image and failure to do so would be an avenue to attack the integrity of the evidence the prosecutors are relying on. Further there needs to be attention given to preserving the digitial evidence of the EM. Although there are free or inexpensive and easy to use tools that can presence the evidence, the difficulty is having the tools in the right place with a suitably trained person to perform the task. It is recommended that an electronic forensic investigator is consulted in these matters to ensure the intergrity of the evidence and an accurate chain of custody.

The second raises more concern. The footage we have made in the laboratory in Dunedin includes positional information: the onboard electronics of the camera are stamping every image with "Lat -36.840740". This is the latitude of Auckland, and is presumably reflects the last time the camera was connected to a GPS unit. Presumably if the camera were aboard as vessel and the link to the GPS unit failed, footage would continue to be collected stamped with the camera's last known position until the issue is fixed. This would provide the defense with an opportunity to question as to whether the vessel was (somehow) absolutely stationary, or whether the data is unreliable. It would be beneficial to require vessels operating camera technology to have a backup GPS unit on board in the event of a failure of the primary GPS unit, which is occasionally encountered (M. Smith Pers Comm.) For evidential purposes we would prefer systems that fail safe.

Explaining and defending the various measurements and methods used in a courtroom situation will inevitably be challenging as there are many steps involved. A great deal of work would be required to develop a brief that would explain matters simply and succinctly, and this would have to be a team effort involving scientists, prosecutors, a statistician and a graphic artist.

The final point is possibly the most important. The experimental measurements described so far have all been made on individual fish lying on a flat, high contrast background and in good lighting, and mostly using the high resolution images collected using the laboratory camera. Accuracy and precision will inevitably suffer under less favourable conditions. Before any attempt is made to use any measurements made from this type of footage in the courtroom we need to collect a lot more about the error rate when it is applied in the real world.

2.8 ERROR RATES

Our final experiment was undertaken to determine the trueness of measurements made on snapper in a more natural setting. This was set up as a blind trial: the fish were simply identified by photograph number and a letter, and the authors had no idea of the identity of each fish when measuring the images.

The fish were presented in random orientation, thrown into the top of a bin already filled with other snapper. A typical image is shown below.

In this photograph the fish are lying on a surface which is not flat, and which offers a poor contrast. The image is made with the laboratory camera at an angle of declination of 30°. The corners of the fish bin are used as the reference rectangle, and neither lighting nor resolution are limiting.

All proxy dimensions that could be clearly seen on each fish were measured unless the viewer subjectively decided that the measurement would be too far out of plane. One hundred and eleven fish images were measured in this way, and the set of measurements were made independently by each author. The fork length of each fish was estimated from each proxy measurement made.

After the measurements were made the trial was unblinded, and the estimated and actual fork lengths of the fish were compared. Table 2 below shows the average trueness figures for the estimates made with each proxy measure, and the standard deviation of this. An average trueness of 1.000 means that the estimated lengths are not systematically biased. Precision is inversely proportional to the standard deviation.

Table 2: Trueness of lengths estimated from images collected in a blind trial

Proxy Measure	Trueness		Standard deviation	
	Graeme	Henry	Graeme	Henry
Total length	1.02	1.03	0.15	0.23
Fork length	0.99	1.05	0.14	0.21
Snout to pelvic origin	1.02	0.69	0.33	0.56
Snout to pectoral origin	0.96	0.88	0.37	0.52
Snout to anal fin	0.92	0.72	0.26	0.43
Snout to mid orbit	0.58	0.83	0.47	0.44
Snout to opercular tooth	0.88	0.91	0.34	0.52
Mid orbit to opercular tooth	0.85	0.84	0.29	0.47
Pelvic fin length		0.72		0.58
Pectoral fin length	1.09	0.91	0.02	0.36
Dorsal origin to anal origin	0.89	0.98	0.25	0.38
Depth at mid orbit		0.64		0.61
Depth at pelvic fin	0.98	0.75	0.28	0.34
Depth at anal fin	0.84	0.91	0.21	0.46

This table shows that (i) many of the proxy measures are performing very poorly in a more realistic setting; (ii) that there is a great deal of variation in the fish lengths estimated from the photographic measurements; and (iii) that the accuracy of estimation is also dependent on the identity of the operator.

In the work described earlier in this paper most of the image interpretation work was done by Graeme rather than Henry, and the benefits of this prior experience are probably reflected in the lower standard deviation obtained by Graeme in Table 2. This suggests that if the method was to be used operationally training and ongoing proficiency testing would be very important – error rates would have to be determined and tracked for each person interpreting the images, and there would be merit in having the images read by several analysts independently.

It is possible to use our data to calculate the smallest length of a snapper which could be unequivocally said to be over the MLS. This will, of course, vary with the identity of the analyst and the proxy measure used. However, for those fish where the total length can be seen in the photo, the smallest fish Graeme could confidently conclude was longer than 250 mm would be 355 mm in real life. We believe that this is probably as good a result as can be obtained, and that with the poorer image quality likely to be encountered in real life this size would increase. For those fish where the full length is not visible the uncertainty would be greatly increased.

2.9 THINKING OUTSIDE THE BOX

We hope it is evident from the discussion above that measurement of snapper from distant oblique images of modest resolution is not a trivial issue.

We want the electronic monitoring systems to deter high-grading, the practice in which the less valuable snapper in the catch are discarded at sea and only the most valuable fish are retained. Because the value of a snapper is proportional to its length this usually means discarding the smaller fish in the catch.

In the footage we have we would have trouble determining conclusively whether any snapper was longer than the minimum legal size of 25 cm unless that fish was actually longer than 35cm: the fish in between 25 and 35 cm in length will fall into a zone of evidential uncertainty. It is the fish within this size range that are most likely to be highgraded. It follows that imagery of the type obtained during the SNA1 trial will be of limited value in enforcing the proscription on dumping snapper of legal size, even if the court accepted the validity of the measurement method.

One potential solution is to ensure that the imagery is collected in a way that would enable accurate fish measurement (see "thinking inside the box" below). However, an alternative, which may be cheaper for all parties in the long run, may be to simply abandon the minimum legal size.

The rationale for having a commercial MLS so undersized snapper can be returned to the sea alive appears rather weak. The undersized snapper caught by a commercial vessel are invariably dead when returned to the water. This has always been the case.

The small fish left on deck, which have been out of the water for some considerable time and have been roughly handled, are then shovelled over the side. We cannot see how any great proportion of such fish are likely to survive this treatment. (NZ House of Representatives, 1937-1938, p.21).

The statutory purpose of the Fisheries Act is "sustainable utilisation". Enforcing the return of dead fish to the water contributes nothing to sustainability and prevents their utilisation. It could be argued that enforcing their discard will prevent the targeting of small fish. But no-one targets small snapper under the QMS anyway, and requiring the discard of small snapper simply minimises the financial disincentive to catch them in the first place.

If the commercial MLS were to be abandoned this would probably drive innovation in unforseen directions, providing incentives to enhance both the marketing of small, plate sized fish and also fishing selectivity. The TACC would need to be increased commensurately to reflect the requirement to count the previously undersized (and therefore unreported) snapper against quota.
Without a commercial MLS the requirement to measure snapper from on-board video would largely disappear.

2.10 THINKING INSIDE THE BOX

Measurement from non-stereoscopic images is greatly simplified if:

1. The camera is close to the subject;

2. Pixel size is less than 1/10th of the unit in which measurements are being made;

3. The subject is lying on a flat surface which contrasts strongly with the fish;

4. The flat surface is marked with a measuring grid;

5. The subject is photographed in good light; and

6. The camera is mounted directly above the fish with the sensor parallel to the plane of the fish being photographed.

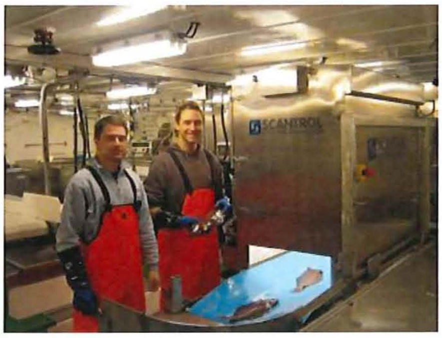
In trying to measure the snapper in the images collected by the Archipelago and Trident systems we are in the same situation as the proverbial motorist in Ireland. He stopped at a crossroads, asked a local for directions, and received the reply "Well Sir, If I wanted to go to Dublin I wouldn't be starting from here".

The distant oblique images collected in the SNA1 trial are usually of snapper lying on other snapper, providing the worst contrast possible, and the systems employed have none of the characteristics listed above.

If we wish to measure snapper from video imagery it would be better to start with better imagery.
In circumstances in which orientation, distance etc are all uncontrolled (as is the case with making photographic measurements of free swimming fish in the sea) stereoscopic imagery is required and measurements can be made from stereoscopic images with great precision (Harvey *et al* (2003)).

In circumstances where more control can be exerted over the positioning of the fish relative to the camera a monoscopic image may suffice, and a number of systems and methods are already in use around the world.

The ideal is probably something akin to the "Catch Meter Box" developed at the Institute of Marine Research in Bergen, Norway.



(See http://www.imr.no/tokt/toktomtaler/okosystemtoktet/toktdagbok_2006/the_catchmeter/en).
In this system the fish are carried on a conveyor beneath the camera, the camera is supplied with it's own standard lighting, and the associated electronics both identify and measure each fish automatically. The developers claim a maximum throughput of 3600 fish per hour, with measurement accuracy of +/- 1.2 % and a 98.6 % accuracy of species assignment. The whole system is built into a box which allows the elimination of stray light. Elimination of stray light is important because the species recognition system is based on shape and colour patterns, and diffuse lighting of a standard colour temperature is essential.

The Catch Meter box was developed for use on research vessels to take over the technical work of catch measurement and enumeration. However, if the conveyor belt was graduated it would also be perfect for court purposes. A layman can interpret an orthogonal photograph of a fish lying on a graduated surface, and mathematical arguments would only be required for fish very close to the MLS.

Archipelago provide a less sophisticated alternative relying on human interpretation as the "EM interpret Length Measurement tool". (Archipelago 2013). This is based upon fish passing down a calibrated chute beneath a fixed camera mounted either 1.5 or 2.5 m directly above. The cross section of the chute is strongly concave, which ensures that the fish move down it in a fore and aft orientation.

Chang *et al* (2009) report on a method of using close oblique digital images for the measurement of tuna on board fishing vessels. This method relies on the fish being posed alongside and in the same plane as a rectangular coloured ruler. The transformations required to correct the images are similar to those employed by Uphotomeasure. The authors claim an accuracy of +/- 3%.

Exerting any form of control over the placement of fish with respect to the camera system is likely to

1. Interfere with thefish handling operation on the deck of the vessel;

2. Impose some capital costs on the vessel owner;

3. Impose an ongoing operational burden on the fishermen; and

4. Require regulatory support.

If (say) the Archipelago measurement system was implemented we would need to create new offences of (i) discarding snapper, regardless of size, otherwise than down the measurement chute; (ii) discarding of snapper, regardless of size, in circumstances when the electronic monitoring camera was not working; and (iii) tampering with the measurement system. We would need to deploy wide angled cameras around the vessel to +ensure that snapper were not being discarded from other points, and we would need to provide or regulate for calibrated chutes to be fitted to the vessels.

Whether or not this approach is worthwhile or even practicable for the smaller vessels in the snapper fleet is questionable. A regulatory switch to a "land everything" regime may be more attractive to some permit holders. The Fisheries Act already contains a provision enabling the Ministry to implement dockside monitoring.

3 Conclusions

1. An issue of great concern in the snapper fishery at present is illegal and unreported high-grading and dumping. The 2014 SNA1 trial demonstrated that on-board video monitoring is capable of monitoring the total quantity of snapper being discarded by a vessel at sea.

2. Compliance needs to give considerable thought to how footage collected in this way can be converted into evidence. One of the many issues requiring consideration is whether the footage can be used to measure the fish. In recent dumping cases, footage of dumping was produced in court. Video footage was sometimes vague. The compelling point was that a witness who was on the vessel described what was happening; the video footage was corroboration of what the witness saw. Footage of snapper being discarded can be used as evidence of illegal activity, if there is direct evidence from a witness. However, because video cameras are set to replace observer coverage in the IEMRS programme (IEMRS, MPI), evidence will rest solely on video footage (IEMRS, MPI).

3. The requirement to measure the snapper being discarded arises becaus the fishery has a commercial minimum legal size. Unless we can determine that a fish is above the MLS footage of a snapper being discarded cannot be used as evidence of illegal activity.

4. The quality and the oblique nature of the imagery collected during the SNA1 trial present major challenges for anyone attempting to measure the snapper seen in the footage. Even under the best conditions it is unlikely that any fish of fork length less than 35 cm can be unequivocally classified as being a fish of legal size. The commercial MLS is 25 cm.

5. In consequence we will be able to adduce little evidence about the fate of the smallest grade of snapper in any proceedings. Fish in the 25 to 35 cm size range are those at greatest risk of high-grading.

6. The methods required to measure fish in this type of footage are complex, and courtroom explanation of any evidence we can adduce will be very challenging.

7. We should re-evaluate whether keeping a commercial MLS for snapper is actually desirable. Our ability to use CCTV as the primary MCS tool in this fishery would be much enhanced if the commercial MLS provision was revoked.

8. If we are stuck with a commercial MLS then we need to ensure that the CCTV systems are installed in a way that facilitates fish measurement. In practice this means either a stereoscopic system, or alternatively ensuring that the discarded fish pass immediately beneath a standard video camera at close range. Neither of the systems installed as part of the SNA1 trial is providing the type of imagery required for this purpose.

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