A Guide to DxO Numbers for Bird Photographers - Ian Wilson PhD (optics)

DxO Labs in Paris provide the most comprehensive measurements of camera sensor and lens performance available online at www.dxomark.com. Understanding the measurements is not always easy and the data has often been misinterpreted leading to controversy and unfortunate attempts to discredit DxO Labs. Part of the problem is the attempt by DxO to aggregate the measurements to produce a single figure of merit called the DxOMark overall score for each camera and lens they test. The overall score is used to rank cameras and lenses based on rigorous underlying measurements but the detail of how the figure of merit is derived is not explained. This naturally opens up a wide field for argument and ill-informed comment on photography forums. The overall score is only useful as a very rough guide to performance and as soon as we start to consider specific use cases, like bird photography, it is of little value. So the first thing we must do is disregard the DxOMark overall score and look at the underlying measurements.

Camera Sensor Performance

Let us begin by looking at the DxO numbers for camera sensors. If you open up the camera Tests and Reviews part of the site, for a particular camera, you will find three viewing options: Scores; Specifications; and Measurements. Scores will open by default and shows a box containing four types of DxO sensor scores (Fig. 1).

Fig. 1. The big picture – DxO sensor scores for the Canon 7DII.

The first is the **Overall Score** already mentioned. The second is the **Portrait (colour depth)** score which is a measure of the colour bit depth at base ISO (usually ISO 100). This is most relevant to studio portrait photography where a wide tonal range is required to record subtle skin tones and product colours. Third is **Landscape (dynamic range)**, a measure of the exposure range from the brightest to the darkest parts of an image that the camera can record at base ISO. As the name suggests, this score is most relevant to landscape photography where it is often important to capture outdoor scenes with an extreme range of brightness. The fourth score is **Sports (low-light ISO)** and is the one most relevant to bird photography. It is based on underlying performance thresholds for signal-to-noise ratio (SNR), dynamic range and colour depth. Each of these parameters decreases with increasing ISO and for acceptable image quality the SNR should remain above 30 decibels (dB), the dynamic range better than 9 units of exposure value (Ev) and the colour bit depth should be greater than 18 bits. As the ISO value is increased, one or more of these image quality measures will fall below the relevant threshold for good image quality and the ISO at which this happens is defined as the DxOMark for the Sports (low-light ISO) metric. For the best cameras it is usually greater than about ISO 2400 and means that the camera should be well-suited to capturing wildlife action such as birds in flight on an overcast day and photographing birds in low light situations such as in shade, early or late in the day, and in a rainforest. For these reasons it is relevant to bird photography and can be used as a guide to comparing camera performance. From a practical point of view, this is not a very sensitive metric and a change of 25% in the low-light ISO value is just noticeable in terms of image quality. When comparing cameras, there are many other factors that also need to be considered such as AF speed, accuracy and sensitivity, exposure metering, frame rate, sensor resolution, build standard, ergonomics and price. The table below shows the DxO Sports (low-light ISO) score for some camera models used by bird photographers.

Camera Model	**Sports (low-light ISO)**
Nikon D5	2434
Nikon D4s	3074
Nikon D810	2853
Nikon D750	2956
Nikon D500	1324
Nikon D7200	1333
Canon 1DxII	3207
Canon 1Dx	2786
Canon 5Ds	2381
Canon 5DIV	Not available at time of publication.
Canon 5DIII	2293
Canon 7DII	1082
Canon 80D	1135

Notice that on this metric, Nikon camera sensors in recent times have usually out-performed the sensors used in Canon cameras. This performance gap is due to the better sensor design and manufacturing technology employed by Nikon's main sensor supplier, Sony. Canon makes a virtue of its vertically integrated camera manufacturing operation but has fallen behind with the performance of its in-house manufactured sensors.

In order to get a better understanding of the value and limitation of the DxOMark for Sports (low-light ISO) it will be necessary to look in greater detail at the measurements; to do this we need to click on the **Measurements** tab. The first window that opens is **ISO Sensitivity** which shows a calibration curve for measured ISO versus the camera ISO; in general there will be a difference indicating that the camera ISO value is often not terribly accurate and is usually greater than the measured ISO. More interesting is the next button labelled **SNR 18%** which reveals a graph of SNR in decibels versus measured ISO (Fig. 2). SNR in decibels is 20 × $\log_{10}$SNR meaning that a SNR = 1 is 0 dB and a SNR = 100 is 40 dB. Also, a difference in SNR of 6 dB means a change in noise level by a factor of 2. The 18% refers to the 'lightness' of the scene; it is the scene brightness perceived by the human eye to be middle grey, that is, half way between black and white. It is used as the brightness standard for 'proper' exposure and in a digital image corresponds to the mid-tone grey with R = G = B = 128 digital numbers (DN). DxO provide two options for viewing the SNR data; 'screen' and 'print'. The screen data are the actual measurements while the print data are the results that would be obtained if the images were down-sampled to 8 MPix (about 3464 × 2309 pixels). Unsurprisingly, the down-sampled images have less noise and therefore a better SNR than the screen data. The print data enables comparison of cameras with sensors having a different number of megapixels and for this reason DxO use this data in their scoring system. In particular, the SNR (print) data can be used to find the ISO value of the 30 dB threshold for good image quality. This is a very useful image quality criterion and should be the first thing we look for when we drill down to find the parameters underlying the DxOMark for action and low-light photography. This is because the SNR is indirectly related to the dynamic range and colour depth; a sensor with a high SNR will also have good dynamic range and colour depth.

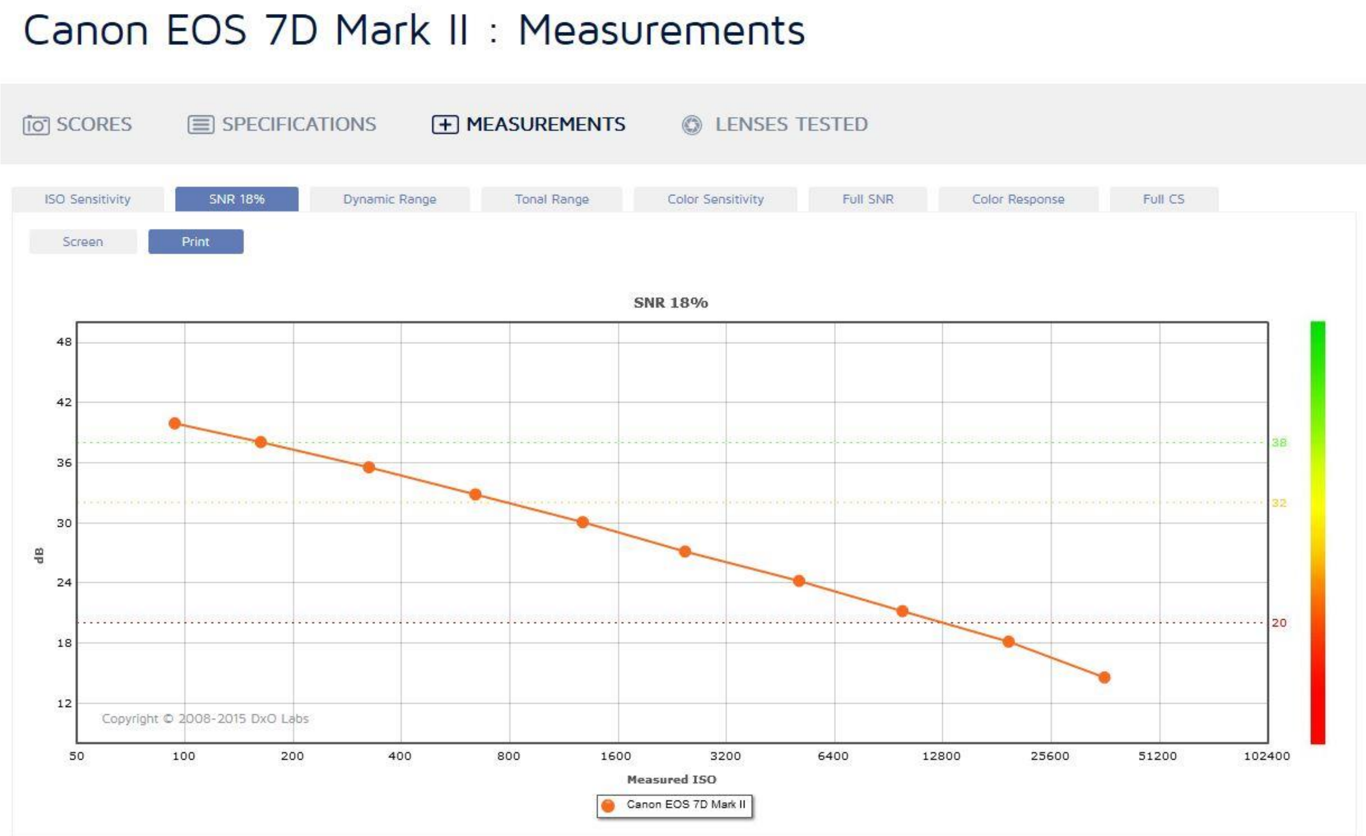

Fig. 2. The SNR of 30 dB is the threshold for good image quality and in this example is reached at about ISO 1300.

The next button under the measurement tab is **Dynamic Range**, one of the threshold parameters used in the Sports (low-light ISO) metric. SNR and dynamic range are related to the extent that a sensor with a high SNR will usually have a wide dynamic range. To better understand the relationship it helps to know how dynamic range is defined. The measurement unit for dynamic range is exposure value Ev which depends on the f-number and exposure time t as follows:

$$Ev = \log_2[(\text{f-number})^2/t] = 3.322 \times \log_{10}[(\text{f-number})^2/t]$$

A difference of 1 Ev corresponds to a change in exposure by a factor of two. The dynamic range is the difference between the exposure value causing the highlights to just blow out and the exposure value corresponding to the lower limit of detection for image features in the shadows. The Ev where the highlights just blow out is easy to understand; it is when the whites reach a screen brightness value of 255 DN. The lower limit of image detection in the blacks depends on the contrast of the image feature and the noise. The detection limit also depends upon the geometry of the image feature, for example, it is easier to see a periodic shape in noise than it is to identify an irregular shape. In the most favourable case, with an object having a contrast of 1 (100%) and a periodic shape, the lower limit to detection is when the number of pixels in the image representing the object equals the number of noise pixels; then the SNR = 1 or in decibels 0 dB. Dynamic range is defined as the difference in exposure value between saturation at Ev (DN = 255) and Ev (SNR = 0 dB). In practical terms it over-states the dynamic range because when the SNR = 0 dB, there is so much noise that it is not possible to identify an object with any certainty and except in the case of a repeating pattern, it is unlikely one would be able to see anything meaningful. Dynamic range defined in this way is sometimes called 'engineering dynamic range' as this is the definition sensor engineers have agreed upon and it is the definition used by DxO Labs.

The question of what is a practical lower limit of SNR for the detection of a feature in a noisy image is an interesting subject worth considering. It was seriously studied in the 1960s in regard to analogue black and white TV and then in medical imaging using X-rays and later ultrasound imaging. A pioneer in the field was Albert Rose who showed that the SNR needed to be about 3 (10 dB) to detect an irregular feature in an image and 5 (14 dB) to distinguish features with 100% certainty. This has become known as the Rose Criterion which states that for the detection of a feature in a noisy image the SNR needs to be greater than 3. Dynamic range based on this criterion is sometimes called 'photographic dynamic range'.

Returning now to the DxO measurements, the dynamic range results are shown in a graph plotted against measured ISO and once again there are graphs showing screen and print data (Fig. 3).

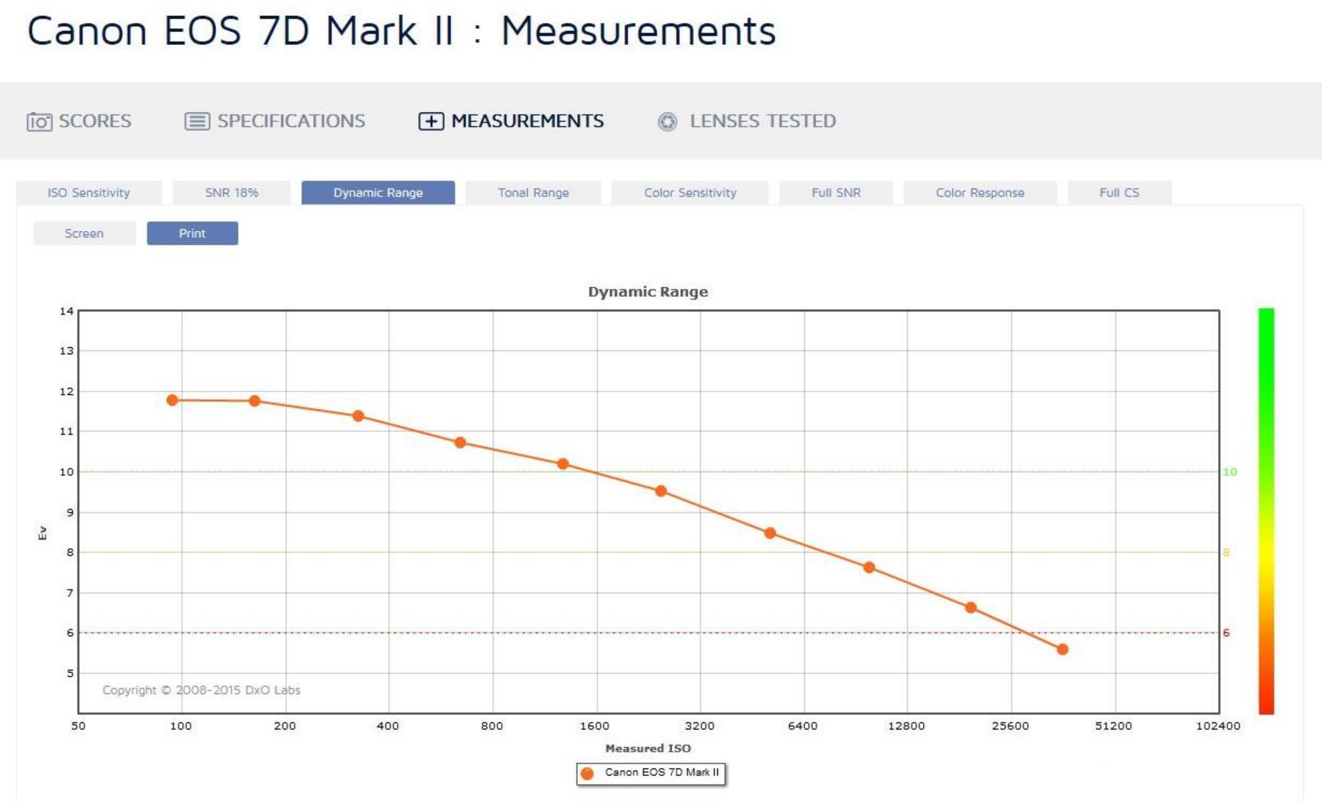

Fig. 3. A dynamic range of 9 Ev is the threshold for good image quality and in this example is reached at about ISO 3500.

Like the SNR, the dynamic range decreases for higher ISO values and it becomes a question of at what point does the dynamic range become unacceptable for bird photography. This will depend upon the subject and lighting, for example a black and white bird in direct sunlight will have a brightness range that exceeds the dynamic range of many cameras even at ISO 100. The same bird captured in poor light with a high ISO will result in an image with limited dynamic range and little scope for recovering detail in the blacks and whites. DxO have chosen 9 Ev (print) as the minimum acceptable dynamic range for good image quality and this is probably about right for bird photography. It allows for about 3.5 Ev above the mid-tone to record the whites and about 5.5 Ev below the mid-tone for the blacks. After adjusting the black and white point in post-processing, the dynamic range will probably be about 8 Ev corresponding to the maximum dynamic range that can be displayed on a good 8-bit per colour channel screen.

The next data set provided by DxO is the **Tonal Range**. This is relevant if you are converting RGB images to black-and-white. It indicates how many shades of grey the camera can capture at different ISO settings. It is not used in the Sports (low-light ISO) metric and as we rarely produce B&W images of birds, we will not make any further comments about tonal range.

Colour Sensitivity is related to tonal range as it indicates how many colour hues a camera can capture at different ISO settings (Fig. 4).

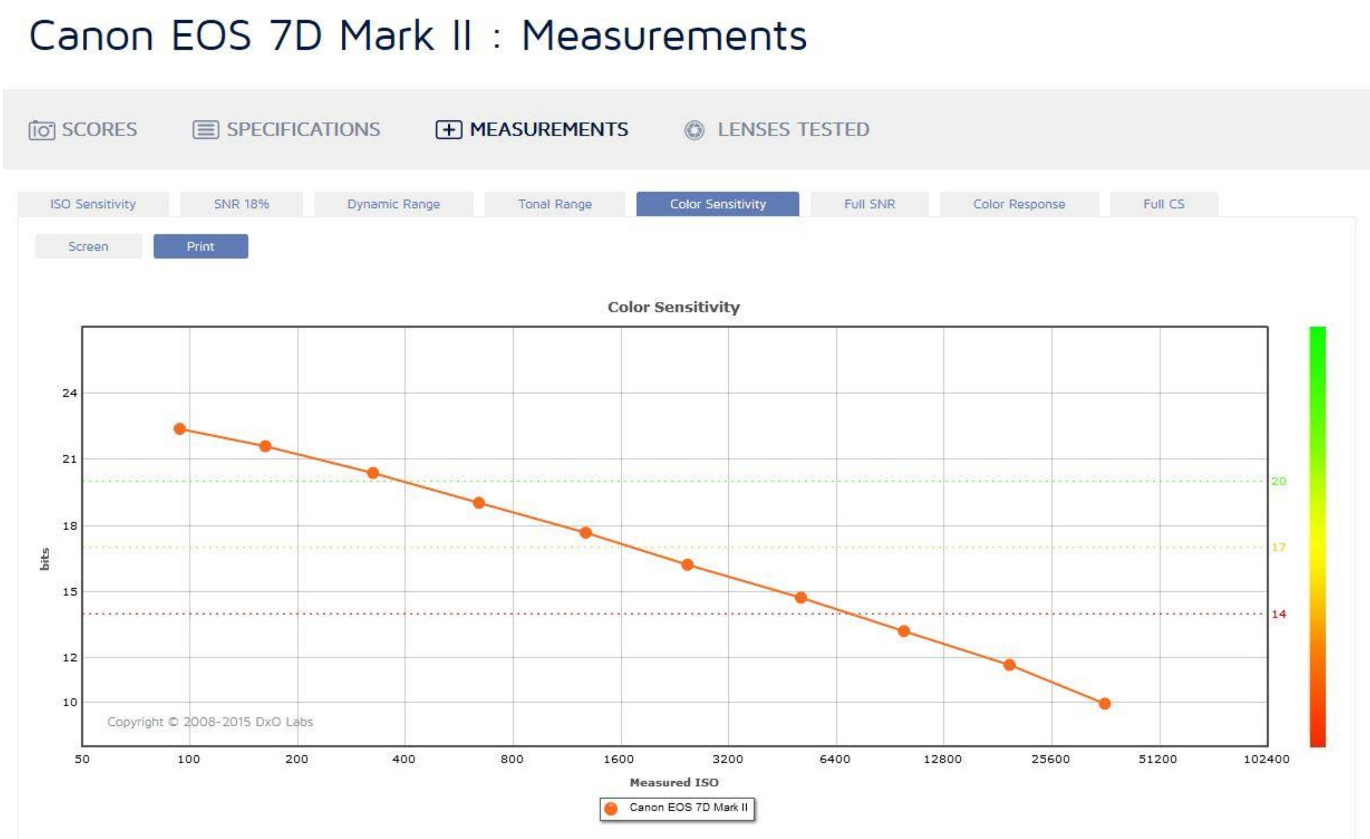

Fig. 4. A colour sensitivity of 18 bits is the threshold for good image quality and in this example is reached at ISO 1082, the critical value determining the Low-light ISO score for the Canon 7DII.

Two hues are considered distinguishable if their difference is greater than the noise. The number of bits required to digitize all the distinguishable hues is defined as the colour sensitivity. For screen output, the maximum colour sensitivity will be 8-bits per colour channel, that is, 24 bits in total, or 16.8 million hues. In practice, the range of hues captured will vary for each colour channel with green having the largest range and red the least. This is because there are twice as many green pixels in the sensor Bayer colour filter array than there are red and blue pixels. The SNR of the green channel is therefore higher than for the other two colours. Also, the colour filters are not perfect and transmit some light from each of the primary colours. For example, in daylight, the red channel usually includes a significant amount of green and a little blue. When the red channel is digitized, one or two bits will be wasted recording the signal of the out-of-channel colours. The practical importance of capturing as much colour bit depth as possible is that it enables subtle changes of hue to be displayed as a smooth transition. When the colour sensitivity is less than about 18 bits, the colour palette available for displaying changes of hue will be limited to the extent that subtle changes will sometimes be rendered as noticeable steps and appear as colour contours in the image. This is known as 'posterization' and must be avoided if possible as it is not easy to deal with in post-processing. A related problem is 'tone separation' where a smoothly varying background begins to break up into little flakes of slightly differing hue and has the appearance of noise.

The DxO Sports (low-light ISO) metric is a good indicator of the suitability of a camera for challenging bird photography assignments. We can look at this in more detail by choosing a typical high ISO and then extract from the DxO numbers the corresponding SNR, dynamic range and colour sensitivity. As an example, we have chosen ISO 2400 (measured) which corresponds to about ISO 3200 for Nikon and Canon camera settings (both manufacturers overstate their ISO settings). This is the typical ISO needed at f/5.6 and 1/3200 sec to properly expose birds in flight in overcast conditions. Fig. 5 shows the SNR versus dynamic range at ISO 2400 and Fig. 6 shows the corresponding colour sensitivity versus dynamic range data. The blue shaded area is below the threshold for good image quality showing us that at this ISO, the cropped sensor cameras D500, D7200, 7DII and 80D, do not meet the requirements.

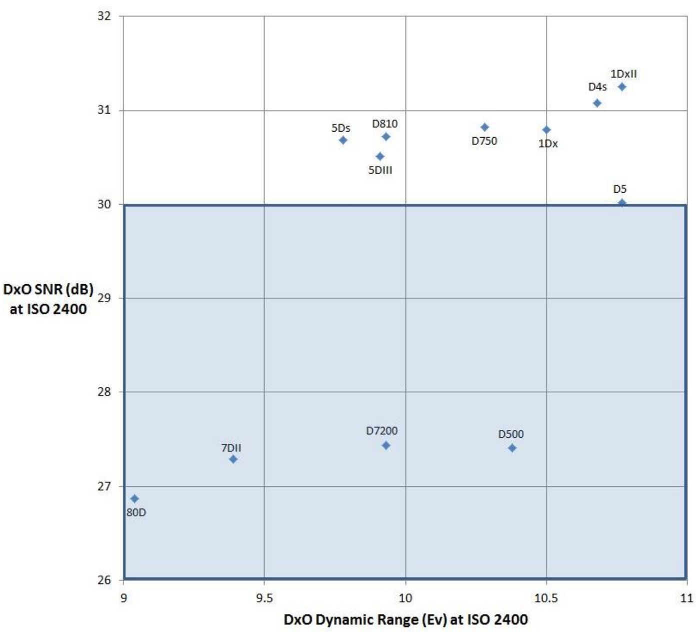

Fig. 5. SNR v Dynamic Range at ISO 2400

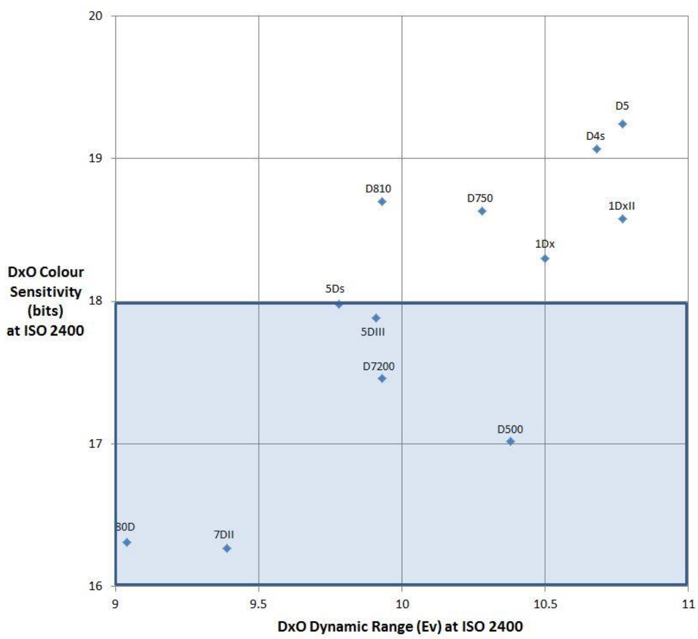

Fig. 6. Colour Sensitivity v Dynamic Range at ISO 2400

Fig. 5 shows that the cropped sensor cameras have about 3 dB more noise (1.4× more noise) than the full frame cameras. Unsurprisingly, it is the full frame flagship cameras D5, D4s, 1DxII and 1Dx that make the grade together with the exceptional full frame D810 and D750. The colour sensitivity of the full frame 5Ds is just below threshold otherwise it too meets the requirements for good image quality at ISO 2400. The data shown in Figs 5–6 illustrates how useful the DxO numbers can be in identifying the best cameras for a particular use case. If we were interested in a different use case, say landscape photography, similar graphs could be constructed at ISO 100 (measured) to identify the cameras best suited to that branch of photography.

This completes the discussion of the measurements underlying the DxO sensor score most relevant to bird photography. We now shift our focus to the DxO lens evaluation tools.

Lens Performance

Lenses are usually evaluated in isolation so that the measurements can be regarded as absolute values which characterize the performance of a particular lens. This is great for ranking lens performance 'on paper' but what we usually want to know is how well a particular lens will perform when used on a particular camera body. This more practical evaluation will allow us to see what difference the number and size of the sensor pixels makes, how the lens performs on a cropped sensor and full-frame sensor, and what is the effect of the micro-lenses, infrared blocking filter, colour filter array and optical low-pass filter that are in the light path in front of the sensor. These optical components are often overlooked but they need to be included because they make a difference to the amount of light reaching the photodiodes in the centre and corners of the field of view and they affect image sharpness.

DxO Labs evaluate the performance of lenses in combination with different camera bodies. This requires a big measurement effort and the accumulation of a large data base of results which has the practical advantages mentioned above. However, the overall DxOMark lens score is not useful because, like the overall sensor score, it is based on an undefined formula and is not sufficiently specific for the way we use telephoto lenses in bird photography. Nevertheless, the underlying measurements are accurate and useful and it is to this data we should look for insights that will tell us how well a particular lens-camera combination will perform.

To see the first set of data we need to select the lens, which will open up a Scores page, and then choose the camera body. The Scores page will show the overall score for the lens-camera combination, which is not very useful, and below this there is a table with some lens metrics (Fig. 7).

Fig. 7. DxO lens metric scores for the Canon 100–400 mm f/4.5–f/5.6 II mounted on the Canon 7DII.

These are of interest; the first one is **Sharpness** in units of Perceptual Megapixels (P-Mpix). This is an attempt to quantify the sharpness of an image over the entire field of view (Fig. 8).

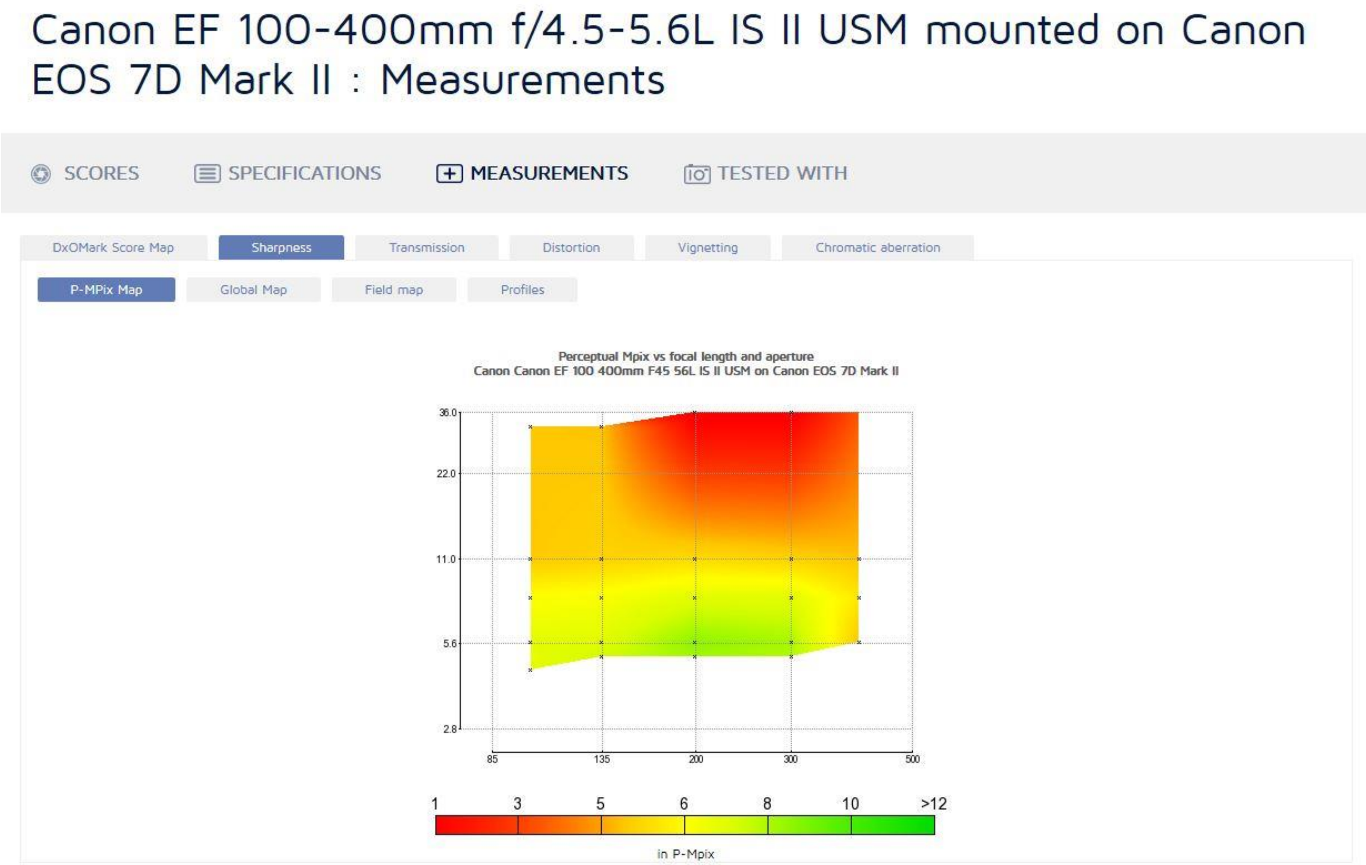

Fig. 8. P-Mpix sharpness map showing that this lens-camera combination is best with the focal length in the range 150–300 mm and aperture about f/5.6.

It is based on the modulation transfer function of the lens and the visual acuity of the human eye. It depends upon the contrast of the test target and the ability of the lens and the eye to resolve fine details in the image. A perfect lens-camera combination would have a P-Mpix metric equal to the number of megapixels in the camera sensor. In practice, the score is always less than this because of residual lens aberrations that can reduce sharpness in the corners of the field of view, the effects of diffraction which can limit overall resolution depending upon the aperture, and then there is the optical low pass filter which is used to deliberately limit the resolution to reduce the contrast of moiré patterns in the parts of images with repetitive fine detail. The main advantage of the P-Mpix score is that it tells us how well matched is a particular lens and camera body. If we consider the P-Mpix as a percentage of the camera sensor megapixels, this will be a measure of the 'goodness' of the match. For example, the Canon 300 mm f/2.8 II lens mounted on a Canon 7DII body has a score of 15 P-Mpix which is 75% of the theoretical best score (20 P-Mpix). Another way to interpret this is to say that the lens and camera can produce an image with the sharpness we would expect from a perfect combination and a 15 Mpix sensor.

The P-Mpix score can have another purpose; in some situations it can provide a ranking of lens performance when there is very little contribution from the optical components mounted in front of the sensor. For example, the Canon 5DsR has the optical low pass filter cancelled so that the P-Mpix score of a lens mounted on this camera will be almost entirely due to the lens. The DxO Labs measurements of lenses tested on the 5DsR provides a convenient way of ranking the sharpness of Canon lenses. Some telephoto lenses of particular interest to bird photographers are shown in the table below.

Sharpness of Lens on Canon 5DsR (50 MPix)		
Canon 300 mm f/2.8 II	45 P-Mpix	90%
Canon 600 mm f/4 II	37	74%
Canon 400 mm f/2.8 II	36	72%
Canon 200–400 mm f/4 (1.4 x out)	33 (200–400 mm)	66%
Canon 200–400 mm f/4 (1.4x in)	18 (280–560 mm)	36%
Canon 500 mm f/4 II	31	62%
Canon 400 mm f/4 DO II	29	58%
Canon 100–400 mm f/4.5–5.6 II	24	48%

The table shows that the 300 mm prime is a 90% match to the 50 Mpix Canon 5DsR body. It means that the lens is almost perfect whereas the sharpness of the 100–400 mm averaged over the zoom range and field of view is not so good. When making this kind of comparison, remember that the P-Mpix value is for full aperture and that for a fair comparison lenses should be compared at the same aperture. For example, the f/4 lenses in the table have a P-Mpix ranging from 29 for the 400 mm f/4 DO II up to 37 for the 600 mm f/4 II.

The next lens metric of interest is the **Transmission**. This is a measure of the amount of light reaching the centre of the focal plane when the lens is used with the aperture wide open. When light passes through a lens a small amount is absorbed by the optical glass and some is reflected back off the optical surfaces resulting in an overall loss compared with the transmission through a perfect lens with 100% transmission. In practice this means that the effective f/No of the lens will not be the same as the f/No determined by the aperture setting. The effective f/No will be a higher number than indicated by the aperture setting. For example, a lens with aperture set to f/2.8 will have an effective f/No of say f/3.3 due to the loss of light. To distinguish this effective f/No from the f/No determined by the aperture setting, another parameter called the T-stop is used. On some lenses, notably cine-camera lenses, there is engraved on the barrel an f/No scale used to set the aperture and hence the depth of field, and a T-stop scale to set the exposure. The difference between the T-stop and f/No is known as the T-stop difference and is a measure of the amount of light lost in transmission in f-stop units. A T-stop difference of 1-stop would be considered poor performance while a T-stop difference less than 0.5-stop is good and what we expect from modern lenses (Fig. 9). In bright light the transmission loss is of little consequence but in bad light and when trying to capture high-speed action – situations we often encounter in bird photography – half a stop more light reaching the sensor and AF system is well worth having.

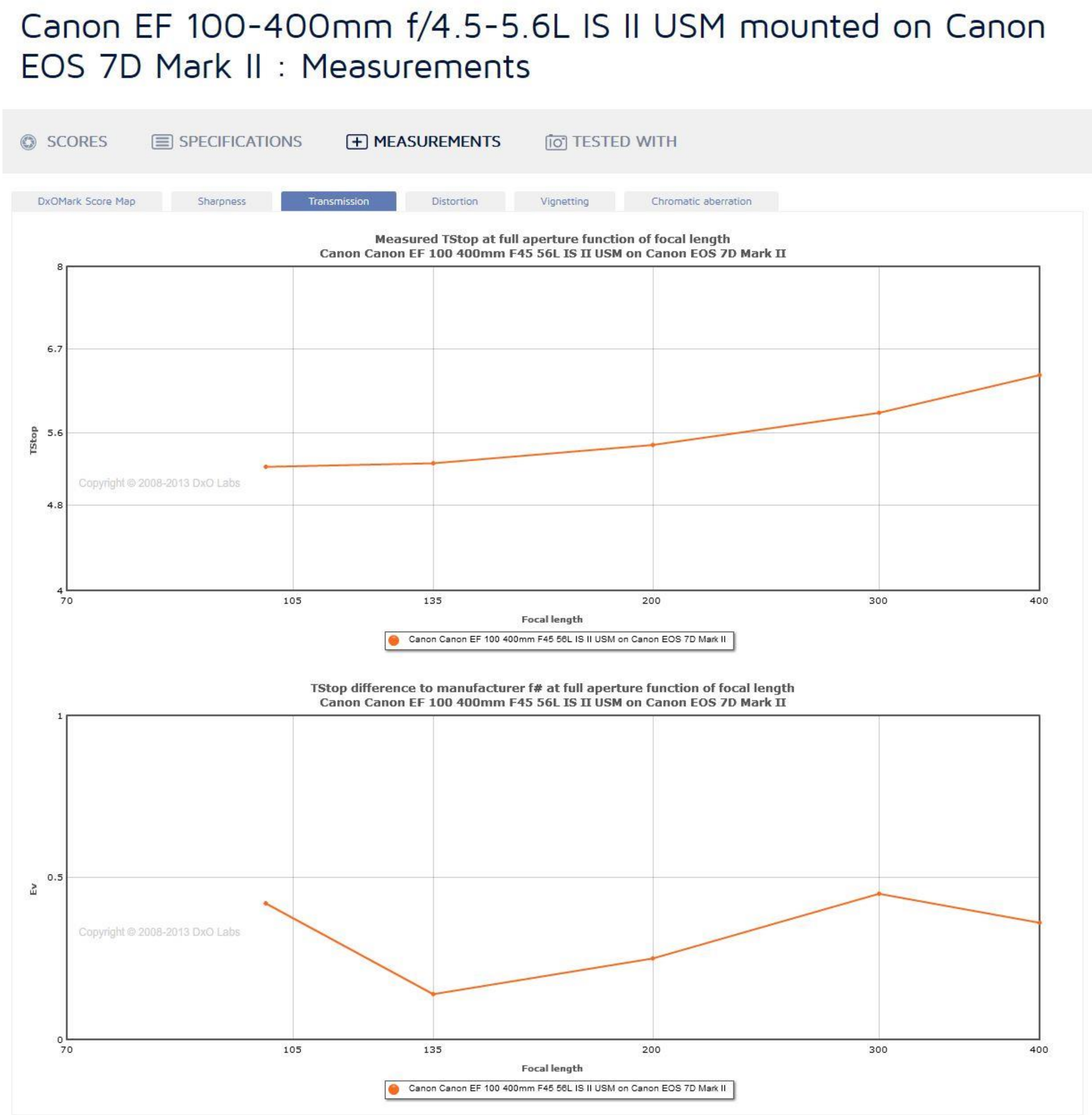

Fig. 9. The T-stop difference (lower graph) throughout the focal length range is excellent indicating that Canon used state-of-the-art anti-reflection coatings on the lens elements.

Distortion is the next lens metric. It is a measure of how faithfully a lens can image a rectangular grid. A perfect lens will form an image of a grid with straight grid lines but one with distortion will image the grid with slightly curved lines. The curvature grows with increasing distance from the centre of the field of view. A curvature of less than one in a hundred (1%) is usually acceptable. Two cases are distinguished, barrel distortion and pin-cushion distortion. Zoom lenses often have barrel distortion at one end of the zoom range and pin-cushion distortion at the other end. Distortion is of most concern to photographers capturing images of the built environment where many man-made structures have straight-line geometric forms. In bird photography, we usually have the bird near the centre of the field of view and in natural environments there are usually few linear features that readily show the effects of distortion. For these reasons, distortion is of little concern and in any case, distortion correction is usually quite good in modern telephoto lenses and can be corrected in post-processing if absolutely necessary.

The next lens metric is **Vignetting** and this too is of little consequence in bird photography. Vignetting is shading in the corners of the field of view and occurs to some extent with all lenses. It is due to the change in perspective of the lens entrance pupil with field angle. The effective area of the entrance pupil is reduced for light coming from the edge of the field of view and therefore less light is transmitted to the corners of the focal plane. A cropped sensor camera has a smaller field of view than a full-frame one and consequently, for a particular lens, will have less vignetting. DxO Labs measure the peripheral illumination and report the results in units of exposure value (Ev) relative to the brightness in the centre of the field of view. -1 Ev corresponds to a factor of two loss of brightness and is typical of the vignetting measured in the corners of a full frame camera. A good lens on a cropped sensor camera should have less than -0.5 Ev loss in the corners. In common with the other lens metrics we have discussed, the optical components mounted in front of the sensor, especially the design of the micro-lens array, can have a small effect on the measured vignetting and for this reason you may notice that the vignetting reported for a particular lens depends upon which camera body is used. At the outset I mentioned that vignetting is of little consequence for bird photographers. This is because we usually place the bird near the centre of the field of view under the centre AF point and we usually crop the image. In any case, vignetting looks much like naturally varying background brightness and, if it is a problem, it can be corrected in post-processing.

The final DxO lens metric is **Chromatic Aberration**. The two most important kinds of chromatic aberration are longitudinal and lateral chromatic aberration also called axial and transverse chromatic aberration. Longitudinal chromatic aberration manifests itself as a variation of focal length with wavelength and to good approximation is the same amount everywhere in the field of view. In practice, it appears as colour fringing around hard edges of image features and looks equally bad over the entire field of view. Fortunately, it is usually well corrected in modern telephoto lenses and is of little concern. On the other hand, lateral chromatic aberration (LCA), caused by slight differences in magnification with wavelength, can sometimes be noticeable as colour fringing toward the edges and corners of the field of view. It can be measured by capturing an image of an array of circular black dots on a white background and analysing the image to find the centre of each dot in the three colour channels. When LCA is measurable, the centre of a dot will have slightly different spatial coordinates depending upon the colour channel. The position of the red and blue channel dots are measured relative to the position of the green channel and the difference is reported in micrometres. DxO provide maps of the LCA that enable us to see how it varies across the field of view with aperture and also, in the case of zoom lenses, with focal length. The DxO chromatic aberration metric is the maximum value measured and for a good lens should be less than the width of a sensor pixel. For example, the Canon 7DII sensor pixels are 4.1 µm so LCA less than this will not be noticeable. Note also that LCA is less of an issue for cropped sensor cameras than full frame cameras and it can vary slightly depending upon the design of the micro-lenses and other optical components mounted in front of the sensor. The latest generation of telephoto lenses use fluorite and extra low-dispersion (ED) glass types developed specifically to control chromatic aberration. Canon recently announced the introduction of an organic Blue Spectrum Refractive (BR) material that practically eliminates chromatic aberration as an issue.

Conclusions

DxO Labs provide a tremendous resource that can be used to help us make better decisions about gear selection. In this article I have tried to show which DxO scores and metrics are most relevant to bird photography but remember there are many other factors that need to be considered along with sensor and lens performance. In particular, a fast and accurate AF system is vitally important but there is, unfortunately, no standard test to enable us to rigorously compare the performance of different camera models and brands. The most useful DxO sensor score is the Low-light ISO metric which depends upon the SNR, dynamic range and colour depth. For bird photography in challenging situations, this metric needs to be greater than about ISO 2400. The most important lens metric for bird photography is the P-Mpix score, a measure of sharpness and which, ideally, needs to be greater than about 66% of the theoretical maximum. Good light transmission to the sensor photodiodes is next in importance; a T-stop difference of less than 0.5-stop is what we want. Distortion, vignetting, and chromatic aberration are of little concern with the latest generation of telephoto lenses and in any case these shortcomings can be corrected in post-processing if necessary.

When it comes to choosing the right gear, remember that bird photography is one of the most difficult branches of wildlife photography and the old adage “you get what you pay for” is generally true. However, the law of diminishing returns also applies and can be used to balance the benefits of small gains in performance against their high cost.