Close Encounters With A Telephoto - Ian J. Wilson BSc(Hons), PhD(optics)

Bird photographers generally want to record images that are as sharp as their gear will allow and to achieve this their camera needs to record fine detail. This generally means the photographer must be equipped with a telephoto lens and be close to the bird. The meaning of being 'close' is relative and depends on many factors. In the context of this article, close means three metres and the subjects are the small bush birds typically found around Melbourne. They provide an interesting case study of how to get the best out of a camera system.

The first challenge is to have plenty of photo opportunities as it will take many shots before one is satisfied. A bird bath in a native plant garden is an ideal situation. If the photographer sits quietly on a chair near the bird bath, most garden birds will be unperturbed. If the photographer is draped with shade cloth with a slot cut for the lens, then even the most timid birds will be relaxed, with some birds landing on the cloth or foraging underneath at one's feet. Hot days are an advantage as many birds will come to bathe and drink. At other times, the photographer will discover there are patterns of visitation by individuals and communities of birds that suggest the most favourable times to be on station. Lighting may also be more favourable at certain times of the day. A monopod is a great advantage for supporting the heavy camera in the sometimes long periods of inactivity and is ideal for tracking agile little birds and getting away quick shots.

The sharpness of an image is the photographer's term for what optical scientists and engineers would call resolution. The resolution limit is a measure of the finest detail that can be recorded in an image. In practice it is a measure of how close points and lines can be in an image and just be resolved. The resolution limit of a camera system depends on a number of factors, some more important than others. In our case study we will try to show how photographers can discover the resolution limit for themselves and how to get the best out of their cameras using a few simple optical principles. The camera system used in the study is a Canon EOS 7D body with EF 300 mm f/2.8L IS II USM telephoto lens. However, the remarks that follow are applicable to telephoto camera systems in general and are not specific to the Canon system except by way of example.

Image Resolution

For well designed and manufactured lenses, the resolution is determined by residual lens aberrations for low f/Nos and diffraction of light from the edge of the aperture stop for high f/Nos. The f/No where the transition occurs from aberration to diffraction limited performance depends on the particular lens design and in the absence of any other consideration, this will be where the best resolution is achieved. The way to find the 'sweet spot' is to shoot an f/No series of a test object that has a lot of fine detail, like a banknote, or if you have one, a resolution test chart. The camera should be mounted on a tripod or similar rigid support for best results. Alternatively, you could find the information on one of the camera test sites on the internet such as http://www.dxomark.com/ You may even be lucky enough to find test data for your lens AND camera body in which case you will not only be able to discover the f/No where the best resolution is achieved but a measure of the resolution limit as well.

The other important factor governing the resolution limit is the sampling interval of the detector array in the camera body. The sampling interval is the pixel spacing and can be readily found in manufacturers' specifications. For example, the Canon EOS 7D has an array measuring 22.3 × 14.9 mm with 5184 × 3456 pixels which gives a sampling interval of 22.3 ÷ 5184 = 0.0043 mm or 4.3 µm. One micrometre (µm) = 0.001 mm. The finest detail that can be resolved by any array is 2× the sampling interval and this is known as the Nyquist resolution. Detail in the image finer than the Nyquist resolution will not be properly resolved but will appear as unwanted moiré interference bands known as aliasing. To avoid this, camera manufacturers include an anti-aliasing filter in front of the detector array. Its function is to filter out detail finer than the Nyquist resolution; in effect, it is a low pass filter. The anti-aliasing filter is not an ideal sharp cut filter and begins to cause the loss of some fine detail even before the Nyquist resolution limit is reached. For the Canon system the Nyquist resolution is 8.6 µm and the anti-aliasing filter is the main factor determining the resolution limit from about f/3.5 to f/10 with a 300 mm lens. For larger f/Nos, the resolution is limited by diffraction and is conveniently described by the Rayleigh resolution limit expressed by the formula:

$$\text{Resolution limit } (\mu m) = 1.22 \times \lambda \times f/No$$

where λ = wavelength, which for green light is about 0.55 µm. The discussion so far is summarized in Fig. 1, which shows how the three components – lens aberrations, sampling interval (anti-aliasing filter) and diffraction – determine the resolution limit.

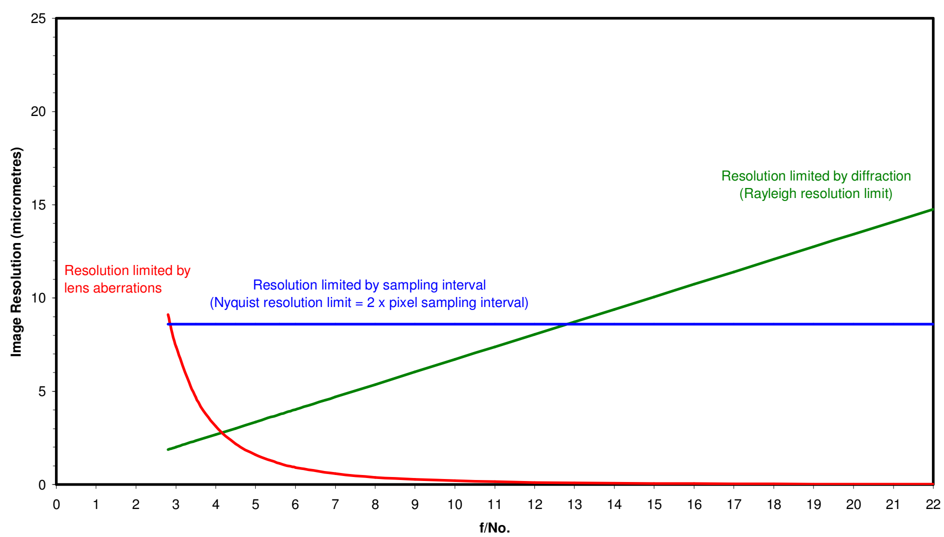

Fig. 1 The resolution limit of a camera system is determined by lens aberrations (——), the detector sampling interval (——) and diffraction (——). Resolution limit due to lens aberrations is indicative only – the graph may not be exact.[1]

The combined effect of these factors for the Canon system is shown in Fig. 2[2]. The graph shows that the finest detail resolved in the image will be about 10 µm when the aperture is set to about f/5 and varies very little from about f/3.5 to f/10. This is confirmed by Roger Clark in his discussion of 'Telephoto Reach and Digital Cameras' http://www.clarkvision.com/articles/telephoto_reach/ His Fig. 9 shows the results of shooting a test chart with the Canon EOS 7D and 300 mm f/2.8 L-series lens. The resolution (sharpness), as expected, is at its best from about f/4 to about f/11, deteriorating for higher f/Nos due to diffraction from the lens aperture stop.

[1] The main residual aberration is assumed to be spherical aberration.

[2] Square root of the sum of the squares of each component.

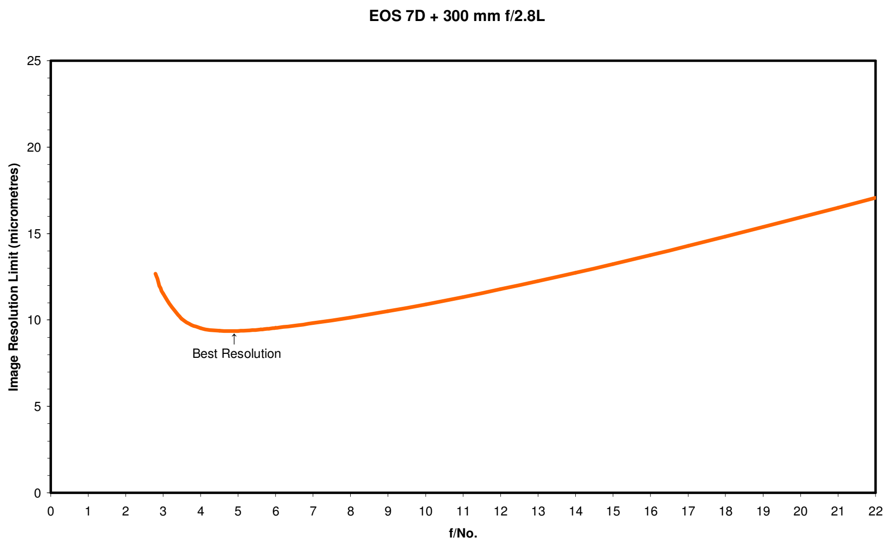

Fig. 2 The image resolution limit due to lens aberrations, anti-aliasing filter and diffraction. The best resolution occurs at the minimum in the curve at about f/5 and is very good from f/3.5 to f/10.

Resolution at the Object

To discover what the resolution limit means in terms of resolving the fine detail of the object (bird), it is necessary to specify the distance to the object and to know the relationship between the size of the object and the size of its image (magnification). The relationship can be written as follows:

Object Distance : Image Distance = Object Size : Image Size

If the object distance = 3000 mm, then the image distance can be found using the lens equation learned at school. For a lens of focal length 300 mm, the image distance = 333 mm, so the ratio:

Object Size : Image Size = 3000 : 333 = 9 : 1

In Fig. 2 it was shown that the finest resolvable detail in the image was approximately 10 µm which corresponds to 9 × 10 µm = 90 µm = 0.09 mm at the object – about the width of a human hair. When the object distance is more than ten times the focal length, a good approximation for the magnification factor is the object distance divided by the focal length, making it unnecessary to use the lens equation. Some examples for the Canon system are shown in the following table.

Object Distance (m)	Object Resolution Limit (mm)
3	0.09
4	0.13
5	0.17
7	0.23
10	0.33
20	0.67

Table 1 Object resolution limit for the Canon EOS 7D + 300 mm f/2.8L lens when the f/No is in the range f/3.5 to about f/10.

Depth of Field

The sharpness of a picture is an important quality that is intimately linked with the depth of field. Although there are some aesthetically pleasing pictures taken with a very small depth of field, our objective is to get as much of the bird in sharp focus as possible. To achieve this, the depth of field needs to be about twice the depth of the bird. For small bush birds, this means the depth of field should be, ideally, at least 50 mm for side-on shots. The depth of field can be found using depth of field tables or an online calculator such as the one at http://www.dofmaster.com/dofjs.html At a range of three metres with the Canon system, the f/No needs to be about f/13 to achieve a depth of field of 50 mm (see Fig. 3). The f/No is outside the sweet spot range and the contrast of fine detail will be so low that resolution will be problematic. Apart from these issues, if the bird is in shade or dappled sunlight, there may not be enough light at f/13 to select a reasonable exposure time and ISO setting for a noise-free image. Clearly, some trade-offs and a little innovation are going to be required to reach the goal.

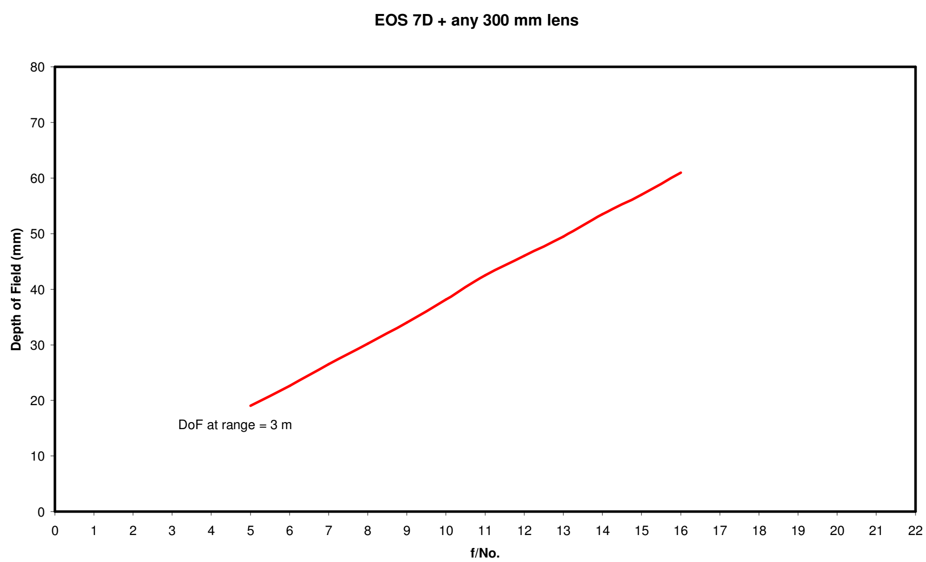

Fig. 3 Depth of field when the range to the bird is 3 m.

Our native plant garden is a bush block in the foothills of the Dandenong Ranges where we have recorded over 70 bird species. Both of our bird baths are somewhat overgrown meaning that at most times of day the visitors are in partial or full shade. The seclusion is much enjoyed by the birds but the lighting is far from ideal for photography. Flash lighting would help but the birds are so agile that shooting in high-speed bursts is essential and then there is an ambition to take pictures of the birds in flight as they come and go. Picture taking under these conditions requires lots of sunlight and the way to get it is with a mirror (see Fig. 4). The birds don't seem to mind the beam of sunlight illuminating their bath, some clearly enjoy it. There is plenty of light for reasonable camera settings at f/10 which provides just enough depth of field to take pictures with most of the little birds in focus. Larger birds like the Red Wattlebird occasionally burst onto the stage but are far too big for the depth of field and the field of view. With the lens aperture set at f/10, at the top of the sweet spot range, there is enough contrast in the image to resolve feather details down to about 0.1 mm. A little image sharpening serves to boost the contrast near the resolution limit.

ISO and Exposure Time

Our next consideration is ISO. This needs to be low enough for the recorded image to be free of detector noise. If the ISO is set too high the noise will begin to spoil resolution and reduce the contrast. Photographers quickly learn from experience how high they can set the ISO before these problems appear or the information can be found online at camera test sites such as http://www.dpreview.com/camerareviews It varies for different camera models, for example, the Canon EOS 7D is essentially noise-free when shooting in RAW up to ISO 640 whereas the new EOS 5D Mk III is noise-free up to about ISO 1600. The importance of correctly setting the ISO was brought to light in our test case situation. One of our bird baths has, in the background, the trunk of a large stringy bark eucalyptus tree. The bark is dark brown to black and is in shade for most of the day. This provides a striking dark bokeh like the background achieved at night using a flash but it also dramatically shows up undesirable camera noise if the ISO is set too high. An example of a picture that is practically noise-free taken with the ISO set at 640 is shown in Fig. 5. This picture, of an immature Eastern Spinebill, also provides a good opportunity to examine the resolution of the camera system. The feather detail in the inset shows well resolved barbs spaced 0.13 mm consistent with a resolution limit of about 0.1 mm.

For close encounters we generally set the exposure time using the well-known rule of thumb that says the shutter speed should be faster than 1/(focal length). This is overkill for image stabilized lenses mounted on a support but it is a useful rule for hand-held shots.

Fig. 4 The writer under shade cloth with mirror on a purpose-built stand reflecting sunlight onto the bird bath.

Fig. 5 Eastern Spinebill (immature). EOS 7D + 300 mm f/2.8L, f/10, 1/500 sec, ISO 640, range 3 m. The inset shows covert feather detail with a 1 mm scale bar. The spacing of the feather barbs is 0.13 mm.

Conclusions

This discussion of close encounters with a telephoto has served to confirm and reinforce what all bird photographers know – to record fine detail, close is better. They also know that all telephoto systems have an optimal aperture range that produces the sharpest images. Most photographers discover this by camera testing or from published test results and then develop their own rules of thumb for the gear they use. This knowledge, in combination with a depth of field table or calculator, enables them to get the best out of their cameras. In this article we reached the same understanding by using the principles of optics to show how the lens aperture controls the depth of field and resolution. We showed there is a trade-off between getting close to resolve fine detail and standing off to maintain an acceptable depth of field, a fast enough shutter speed to minimize motion blur and a low enough ISO setting to control detector noise. We have used a Canon system to illustrate how these tensions are balanced to achieve best results for small bush birds at close range but the principles apply to other bird photography situations and to other telephoto systems. As a result of this study we were able to produce our own rules of thumb for the Canon system used in good light (see Table 2). Other camera and lens combinations will be a bit different but if you follow the line of thought outlined in this article, it will not be too difficult to work out similar rules to get the best results from your gear.

Situation	**Optimal f/No.**	**Exposure Time (sec)**	**ISO**
General Rule	f/3.5 – f/10	1/320 or faster	640 or less
Close encounters Range 3–4 m	f/10	1/320 or faster	640 or less
Range 4–10 m	f/10 – f/5.6	1/320 or faster	640 or less
Range 10 m or more	f/5.6	1/320 or faster	640 or less
Birds in flight	f/3.5	As fast as aperture priority will allow	640

Table 2 Optimal camera settings for picture taking with the Canon EOS 7D and 300 mm f/2.8 prime lens. Longer exposure times can be used if the camera is well supported such as on a monopod or tripod.

The case study was more interesting than first expected because, as it turned out, extreme measures were required to produce acceptable pictures. Who would have thought that an aperture of f/10 would be needed to photograph small birds at close range?

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