

Macro Focus Stacking ‘In Depth’

v1.1 Dec 17, 2018

One of the big features of the Nikon D850 (and the new Z 6 and Z 7 cameras) is the ability to automate the creation of focus stacks. Before the D850, focus stacks were built manually. One focused on the nearest important image element and made the first frame of the stack. The lens would be re-focused so each subsequent frame has a depth-of-field that overlaps that of the previous frame! This usually involved noting the lens focal length and subject distance, finding the appropriate entry in DoF tables, then manually refocusing for each frame. I often use a small laser rangefinder to accurately find the desired points of focus. I’ve done this for several years; it works well but takes a fair amount of time to work through a stack.

For the traditional ‘Grand Landscape’ I love, I highly recommend Steve Perry’s e-book “Secrets to the Nikon Autofocus System”, available at his web site [Back Country Gallery](http://BackCountryGallery.com). It covers all aspects of the Nikon focus system, including focus stacks, and the use of tripods and software used to render stacks. (It’s more than recommended; it’s a ‘must read’ for Nikon owners!)

Having this process automated in-camera is a true advancement. Modern digital cameras always know (1) what f/stop you’ve chosen, (2) what focal length is being used (fixed or zoom) and (3) the location of the focal point. All the elements needed for creating a focus stack are known to the camera. With the D850, Z 6 and Z 7, internal software can now build a stack in mere seconds; truly a minor miracle.

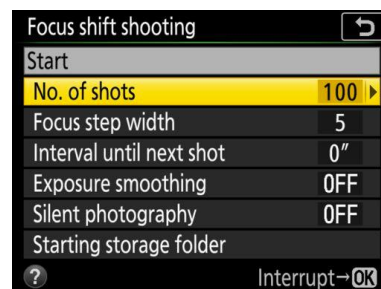
The basic approach is as follows:

1. The camera is focused on the nearest feature that must be in focus.
2. The Focus Shift menu is used to set a few of parameters.
3. ‘Start’ is selected, and the OK button pressed to begin the stacking process.

The camera takes multiple frames, automatically refocusing at increasing distance for each subsequent frame. The stack process stops when the preset number of frames is reached, as set in the menu, or the lens reaches infinity. If you watch the top LCD panel, a ‘count down’ that starts with the number of shots selected is displayed. You’ll hear the shutter close when the stack ends.

This is an image of the Focus Shift menu. There are 6 items that the photographer can set.

1. Number of shots
2. Focus step width
3. Interval until next shot
4. Exposure smoothing
5. Silent photography
6. Starting storage folder



For macro photography, the options are more complicated. If your subject is only a few inches in depth, or less, you really do not want the camera working through frames out to infinity. Some way to estimate the proper number of frames is needed, just what this document is about.

General Settings

The bottom four settings are likely to be the same for all situations, so let's cover them first.

Interval until next shot – You can use this setting, 1 or 2 seconds, if you want to allow the camera to be free of shutter and mirror vibrations. But if you choose 'Silent photography' leave this at 0. If using stacks for subjects needing electronic flash, use this to allow the unit to recharge.

Exposure smoothing – If you are shooting a deep stack under changing lighting conditions, the D850 will adjust exposure automatically. (The camera must be in one of the auto exposure modes, not manual.) If you are using Silent photography, the individual frame are captured quite quickly.

Silent photography – I suggest that you set this to 'ON'. In silent mode, the mirror is locked up, and the frames captured electronically. No shutter or mirror slap! With none of these vibrations, the shooting interval can be 0.

Starting storage folder – I do not use this option. It has to be reset for each sequence, and is more of a chore than an advantage. So how do you tell where one stack ends and the next begins? After each stack, take one frame with your hand in front of the lens. Stacks will be clearly apparent in Bridge or Lightroom.

Grand Landscapes

I admit it ... I was drawn to landscape photography by the incredible work of Ansel Adams. His deep depth-of-field and rich textures really made me feel present in the landscape, not the mere observer of a photograph.

As a photographer you might immediately ask yourself several very pertinent questions:

- What f/stop should I use?
- How many shots are really needed?
- What does the appropriate 'Focus step width' value?

The answers are ... it depends. For the normal landscape, DoF tables work well, and only a few frames are usually needed. For macro photography, DoF table are not generally reliable; they are based on simplified formulas and almost never address the working distances of inches used in macro photography. At a reproduction ratio of 1:1, depth of field is extremely shallow and dozens if not hundreds of frames may be needed to achieve an effective DoF of 3 inches.

I'll cut to the chase here. For normal landscape photography, Steve's recommendation for Number of shots, 20, and Focus step width, 4, works well! I've used these setting for lenses from 16mm to 70mm, at f/2.8 through f/11. All worked correctly! I have found that the stacking process frequently stops at infinity with less than 10 frames. Even then, the last 2 or 3 frames may not be used as some lenses focuses beyond infinity. In fact, at 24mm and f/8, you may find stacks of only 2 or 3 frames!

But note! Focus stacking no longer requires small apertures to obtain deep depth-of-field. Small f/stops have issues with diffraction reducing sharpness. Use the f/stop that gives you the sharpest image! The stacking process builds depth-of-field for you. In general, I find f/5.6 works well. Steve's e-book suggests a way to find the best f/stop to use for your lenses.

Macro Photography

Macro photography is different. You will seldom if ever need to generate frames to infinity. You will typically have a small subject with a very specific depth dimension: an insect, a small patch of lichens, or a crystal. Depending on the reproduction ratio and subject distance, depth-of-field may be very, very small, measured in fractions of an inch, not feet. The number of frames needed may be quite large. If your subject has a depth of 4 inches and your depth-of-field is $\frac{1}{4}$ inch, you need to shoot about 16 frames. You would not want the camera to keep shooting at $\frac{1}{4}$ inch intervals out to infinity! Nor would you want to shoot too few frames, leaving the distant parts of the scene out-of-focus. Setting a realistic number of frames is important.

What we need to know then is the number of frames that encompasses the full depth of the subject. What complicates this is that depth-of-field tables generally do not cover the close distances used in macro photography. While the camera may be able to calculate the correct step width, it does not know what total depth is required for your image and what the correct number of frames is needed.

Rather than use trial-and-error, I decided to do the experiment; create a table of values that work. In the field, I can measure the physical depth of the scene, focus on the closest element, then use the table to set the necessary number of frames.

Such a table would be based on the specific focal length and f/stop set on the macro lens. I use a Nikon 105mm f/2.8 Micro-Nikkor. It is sharp at f/8, and this f/stop gives a reasonable depth-of-field before diffraction sets in. And it can get to 1:1 reproduction ratio without extension tubes or close-up filters.

The rules of depth-of-field tell me that the shallowest value would be (1) at maximum magnification, in this case 1:1, and (2) at the closest point of focus for the stack. (Depth-of-field tables will show that as the subject distance get farther away, the depth-of-field increases, though perhaps only slightly.) The correct Focus step width value for the closest part of the subject will then work for the entire subject depth. Yes, we may have more frames than technically necessary, but we will not lose any sharpness.

All we need to do is determine the proper focus step width for f/8 at 1:1.

My usual DoF table shows zero DoF for these values. A quick look at a depth-of-field table for macro work suggests that the DoF for f/8, 105mm at closest focus is ± 0.1 inch. If correct, we would theoretically need 10 frames for 1" subject, 60 frames for a 6" subject, and 120 frames for 12" subject.

The problem is that we do not know what the Focus step width numbers really mean. Does a value of 1 result in a step of 0.2"? Or is it a value of 2, 3, 4 or higher? More importantly, we do not even know if this DoF table even gets it right! We need to use real gear to figure this out.

This is what we need to know: what is the best Focus step width number for my 105mm lens at f/8.

We get to do some experiments!

The Experiment

We're going to do one 'experiment', then produce several calibration curves. The experiment is to determine the best Focus step width for our most demanding macro photography, 1:1. The calibration runs then let us determine the number of frames needed to achieve a specific DoF for several reproduction ratios.

Setup

The setup is quite simple. A ruler set at a shallow angle is photographed. The macro lens is set to the 1:1 reproduction ratio, and the camera secured on a tripod in portrait orientation. The camera and tripod are physically positioned so the zero end of the ruler is in sharp focus at the bottom of the frame, close to the camera, and the far end of the ruler visible, but out-of-focus, at the top of the frame. Live view and focus peaking facilitate this. I select f/8, then change the ISO to achieve a suitable shutter speed. Since we will be creating some deep stacks, a faster shutter speed gets the stack done more quickly. Since we use a tripod, a fast shutter speed is not needed for sharpness, only a faster stack.

My 'ruler' happens to be from the Lens Align tool kit from [Michael Tapes Design](#) that is used to calibrate accurate focus for certain lenses. It's very contrasty and makes banding easy to see. It is not directly calibrated in inches, but by noting which boxed numbers along the edges are in focus, we can physically measure the depth-of-field.

Lastly, measure the slope of the ruler. We'll need this value later. My ruler has a slope of 20 degrees. (If you have an iPhone, open the Compass or Measure app and swipe the compass display left to reveal an angle measuring display. Line it up with your ruler and note the number of degrees.)

Procedure

Set the camera to shoot large, optimal quality, JPG fine images, aka Large JPG*. We use JPG* because RAW image processing is not needed, and large, optimal quality, fine uses the least compression. There will be no in-camera downsizing that might obscure the banding. (You might choose TIFF for the same reason, but file sizes are bigger.) Auto-Focus must be On. Start with an empty memory card.

We need to test a variety of values for the Focus step width. Steve Perry tells us that a value of 4 will work, so let's test values of 3,4 and 5. (If Steve is right, 4 will work; we will bracket this to be sure.) Set the number of frames to 40. In this experiment we're looking for the biggest step value that does not produce banding. We're only looking to see if banding is happening here; we're not concerned with depth yet. That's next

Open the Focus Step Shooting item near the bottom of the Shooting menu. Make the follow settings for the first run:

- Number of shots: 40
- Focus step width: 3
- Interval until next shot: 0
- Exposure smoothing: Off
- Silent photography: On
- Starting storage folder: (Skip)

For this starting test, no need to set a Starting storage folder. We'll load out the test images for an initial evaluation.

After you verify that the camera is positioned properly, and the nearest marking on the ruler is in focus, move the menu selection to the top of the menu for Start, tap the OK button. The camera starts making images in a few seconds. The green light on the back of the camera will flash intermittently. With Silent photography set to On, the mirror only lifts once, and the shutter remains open. It's fast and silent! Watch the count down on the top LCD.

When finished, cover the lens with your hand and take one additional frame. This step makes it easy to see where the sequence ends.

Now refocus the camera back to the zero end of the ruler. Open the Focus step shooting menu again and change the focus step width to 4. Move the menu selection to Start, press the OK button. When finished, take another image of your hand.

Repeat these steps with Focus step width set to 5.

We're done! Turn the camera off and remove the storage card. Move the images to your computer. I like to place these in a new folder with a descriptive name, e.g. StackWidthTest. We'll likely delete all the images once the test is complete.

This is one frame from one of the stacks. The depth is just too narrow to measure accurately, which is why we will merge a large number of frame before trying to establish focus depth.

Post processing

The images are ready to be stacked. While it may be disappointing that the camera does not do this for you, there are excellent reasons to use third party tools. I use both Photoshop and Helicon Focus. Both do very well at rendering stacks. Helicon Focus has some useful retouching tools that Photoshop lacks, and can produce a DNG output file from Nikon's NEF images. The DNG can then be further processed in Adobe Camera Raw.

Here are the 'in-a-nutshell' versions of how to render the stacks in Photoshop and Helicon Focus.

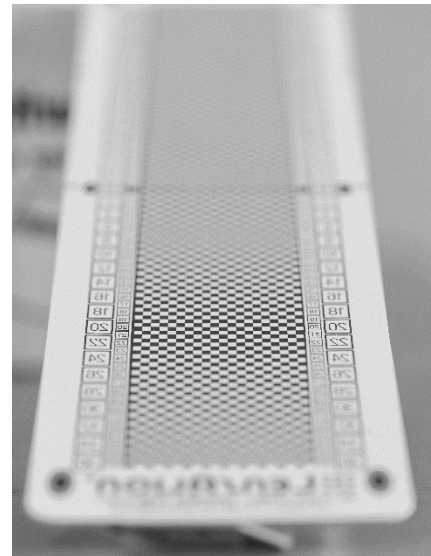
Rendering using a Photoshop workflow

In Bridge, navigate to the StackWidthTest folder. Select the first image in the first set, then Shift+Click the image just before your first 'hand' image. You should have 40 images selected, as indicated at the lower left of the Bridge window. Then use the menu sequence

Tools > Photoshop > Open Files in Photoshop layers ...

When Photoshop has finished opening, select all the layers in the Layers Panel, then use the menu sequence

Edit > Auto-Align Layers ... Choose the 'Auto' option and Click OK.



Tip: I have found that Photoshop does an excellent job of auto-aligning stacks. But many lenses change magnification slightly as you change focus. This is common. After alignment is done, some frames are actually smaller than others!

To see this effect, turn off the visibility of all the layers except the bottom-most layer. (Just Alt + Click the 'eye' icon for the bottom layer. If you see a white border around the image, use the menu sequence

Image > Trim

then select the 'Transparent pixels' option at the top. Click OK. Turn the visibility of all the layers back on ... Alt + Click the bottom eye icon again.

This trims all the layers and the rendered image is sharp across the full width. Without this step, the edges of the rendered stack would be blurry. This could be later cropped, of course. With this issue in mind, you might want compose stacks with some 'extra' pixels at the edges.

With all the layers visible and selected, the menu sequence

Edit > Auto Blend Layers ...

will render the stack. In the dialog, be sure *Stack Images* is selected, as is *Seamless Tones and Colors*. The *Content Aware Fill* option is not necessary. (And it does not solve the edge problem described above.)

When finished, each layer will be masked with black to exclude un-sharp areas. Flatten the image and save as a JPG back to the source folder. When you save the image, give it a meaningful name, i.e. StepWidth3.jpg .

Repeat for the remaining two sets of frames. You should end up with three 'final' images:

StepWidth3.jpg StepWidth4.jpg StepWidth5.jpg

Rendering using a Helicon Focus workflow

Start Helicon Focus and use the *File > Open* menu sequence to navigate to and select the first 40 image set in the StackWidthTest folder. Or you can use drag-and-drop to place the images in the Helicon Focus window.

Once the files are loaded, choose a rendering method. I have had good success with Method B, using the default settings of Radius 8, Smoothing 4. Click the Render button. Once finished, save as a JPG image to the source folder. Helicon Focus suggests a file name based on the last filename and rendering settings. But I suggest using similar names as above. If you want to try both Photoshop and Helicon Focus, be sure to modify the Helicon names so they are different. For example:

StepWidth3H.jpg StepWidth4H.jpg StepWidth5H.jpg

Evaluating the Results

You can use Bridge or any other viewer that will let you zoom to 100% for evaluation. Bridge's Preview pane will let you open all three images for side-by-side comparison. We're looking for focus banding in the closest part of the image.

My findings were that a Focus step width of 5 produced some minor banding. But not even minor banding was seen in values of 4 or 3. I now use 4 for all my stacks. Hey! Steve was right! (But then I use the same lens; your mileage may vary.)

Calibration

Now we know the proper Focus step width settings for band-free stacking. To produce sets of calibration tables, we use a process is like the above; we just need deeper stacks. Here's a suggestion:

- Number of shots: 100
- Focus step width: 4
- Interval until next shot: 0
- Exposure smoothing: Off
- Silent photography: On
- Starting storage folder: (Skip)

Having worked through this process several times, I found reproduction ratios of **1:2**, **1:3** and **1:4** to be suitable for my macro work. Life size (**1:1**) is just too shallow, even at 100 frames.

Start by setting your lens to a 1:2 reproduction ratio. (Most true macro lenses include both focus distance and the reproduction ratio on the lens barrel.)

Position your camera and tripod as above: closest ruler markings in focus. Bring up the Focus shift menu and adjust the settings as shown. Run the 100 image stack. Don't forget one image of your hand at the end!

Reset your lens to a 1:3 reproduction ratio and reposition the camera and tripod to bring the near end of the ruler into focus. You will have to move them back farther from the ruler. Repeat the 100 image stack.

Repeat for the 1:4 reproduction ratio.

Rendering

You now have three, 100 frame stacks on your memory card. I suggest when moving them to your computer, creating a new folder for each stack. For each, we're going to render 10 ever-widening subsets.

This is the set of 10 renderings you will need. Each render is 10 frames wider than the previous set. There's nothing special about 10 added frames per set; you could use 5, but then twice the work.

Save each rendered set with a suitable file name. For example, at a reproduction ratio of 1:2, the first set of frames, 1 to 10, might be named RR12Set1.jpg. The table shows all 10 subsets and suggested names.

You will do this for all three reproduction ratios.

Render Subset	Frames to Render	File Name
1	1 – 10	RR12_Set1.jpg
2	1 – 20	RR12_Set2.jpg
3	1 – 30	RR12_Set3.jpg
4	1 – 40	RR12_Set4.jpg
5	1 – 50	RR12_Set5.jpg
6	1 – 60	RR12_Set6.jpg
7	1 – 70	RR12_Set7.jpg
8	1 – 80	RR12_Set8.jpg
9	1 – 90	RR12_Set9.jpg
10	1 – 100	RR12_Set10.jpg

The full set of filenames are shown in the table below.

Render Subset	Frames to Render	File Name RR = 1:2	File Name RR = 1:3	File Name RR = 1:4
1	1 – 10	RR12_Set1.jpg	RR13_Set1.jpg	RR14_Set1.jpg
2	1 – 20	RR12_Set2.jpg	RR13_Set2.jpg	RR14_Set2.jpg
3	1 – 30	RR12_Set3.jpg	RR13_Set3.jpg	RR14_Set3.jpg
4	1 – 40	RR12_Set4.jpg	RR13_Set4.jpg	RR14_Set4.jpg
5	1 – 50	RR12_Set5.jpg	RR13_Set5.jpg	RR14_Set5.jpg
6	1 – 60	RR12_Set6.jpg	RR13_Set6.jpg	RR14_Set6.jpg
7	1 – 70	RR12_Set7.jpg	RR13_Set7.jpg	RR14_Set7.jpg
8	1 – 80	RR12_Set8.jpg	RR13_Set8.jpg	RR14_Set8.jpg
9	1 – 90	RR12_Set9.jpg	RR13_Set9.jpg	RR14_Set9.jpg
10	1 – 100	RR12_Set10.jpg	RR13_Set10.jpg	RR14_Set10.jpg

Yes, it's tedious. Yes, it takes some time. Yes, it can get confusing. And, yes, it pays off! Only one more step ... measuring the actual depth-of-field.

Measurement

When all the above steps have been taken, you will have 30 rendered images; 10 at each of the three reproduction ratios. All that's left is to look through the images and read off the actual depth-of-field in each. Since each should start exactly at 0 on the ruler, just find the upper distance that's in focus. (But frankly, several of my test images did not show accurate focus on the 0 line. Simply subtract the starting in-focus distance from the top in-focus distance.) Using the Lens Align ruler, I simply looked at my image stacks and physically measured the in-focus segment of the ruler with a tape measure.

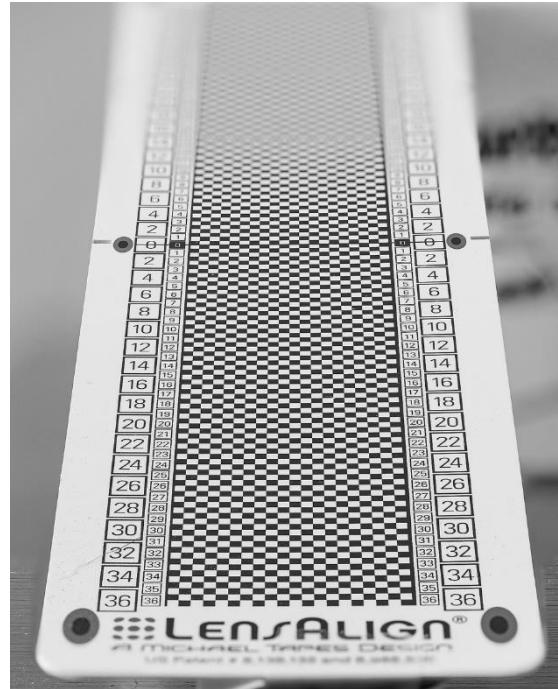
This image is from a 50 frame stack at the 1:3 reproduction ratio.

Note that on this LenAlign ruler, the large squares are 1/4 inch wide, and the small ones 1/8 inch wide. The checkerboard pattern makes it easy to determine which areas are in focus, and if banding has occurred.

The actual depth measurement, in inches, is done by looking at the image on-screen, finding the in-focus squares near and far, then measuring that distance on the LensAlign ruler.

If you use an actual ruler, you could read the depth directly, but finding focus areas might be more difficult. It's easy to try several targets and find one that works best for you.

As you read off these values from the images, enter them in a spreadsheet program, such as Excel or Google Sheets. Since my ruler was angled at 20 degrees, the 'true' linear depth from front to back was slightly less. This is simply the values you read from the ruler multiplied by the cosine() of 20 degrees.



Original data:

	1:2	1:3	1:4
0	0.00	0.00	0.00
10	0.35	0.63	1.50
20	0.75	1.50	3.35
30	1.25	2.45	5.60
40	1.75	3.45	8.20
50	2.30	4.50	11.00
60	2.90	5.80	
70	3.50	7.25	
80	4.25	8.85	
90	5.00	10.50	
100	5.85		

After COS(20°) adjustment

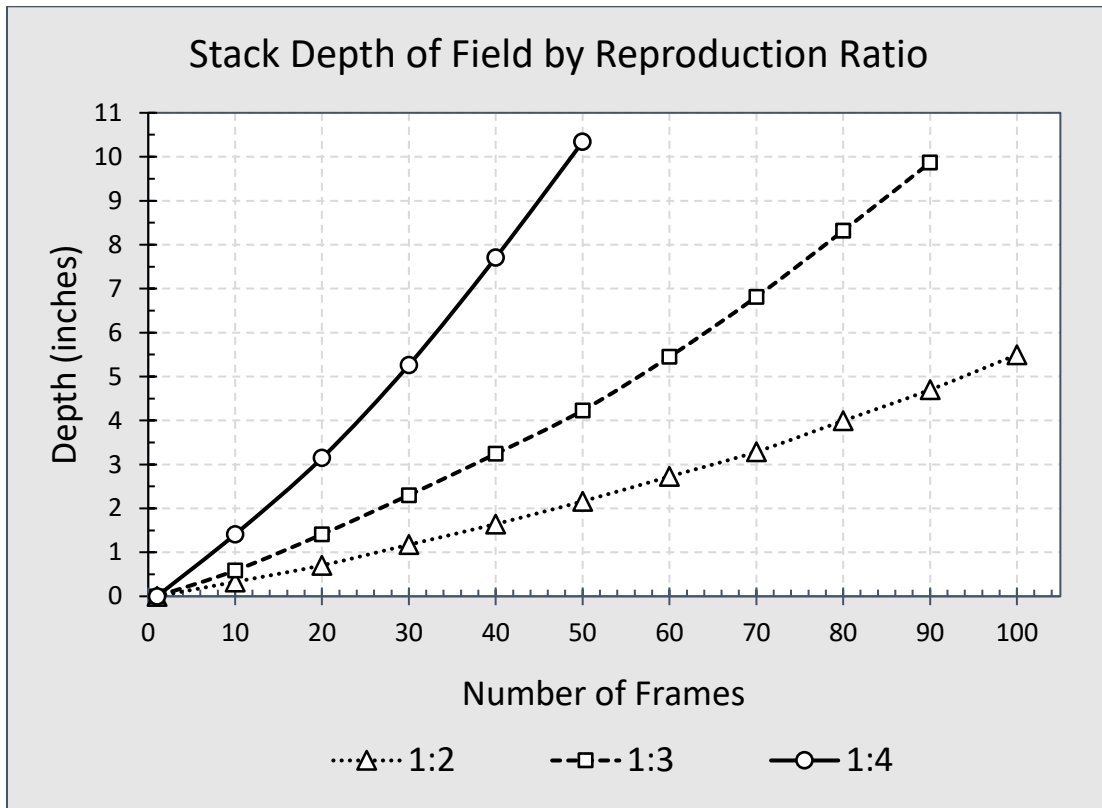
	1:2	1:3	1:4
0	0.00	0.00	0.00
10	0.33	0.59	1.41
20	0.70	1.41	3.15
30	1.17	2.30	5.26
40	1.64	3.24	7.71
50	2.16	4.23	10.34
60	2.73	5.45	
70	3.29	6.81	
80	3.99	8.32	
90	4.70	9.87	
100	5.50		

Couple of things to note:

- In Excel, the cosine() function works with angles in radians. If you measured degrees, the Excel in-cell function is COS(RADIANS(N)), when N is your ruler angle in degrees.
- I added a 'zero' value at the top of the table. This is not really necessary, but it will make plots of the data look better.

- At reproduction ratios of 1:3 and 1:4, the farthest in-focus distance was longer than my ruler. Ten inches is just fine for me. Use a longer ruler if you need to!
- At 1:2, 100 frames held 5.5 inches of depth. Yes, I should repeat with a longer ruler.

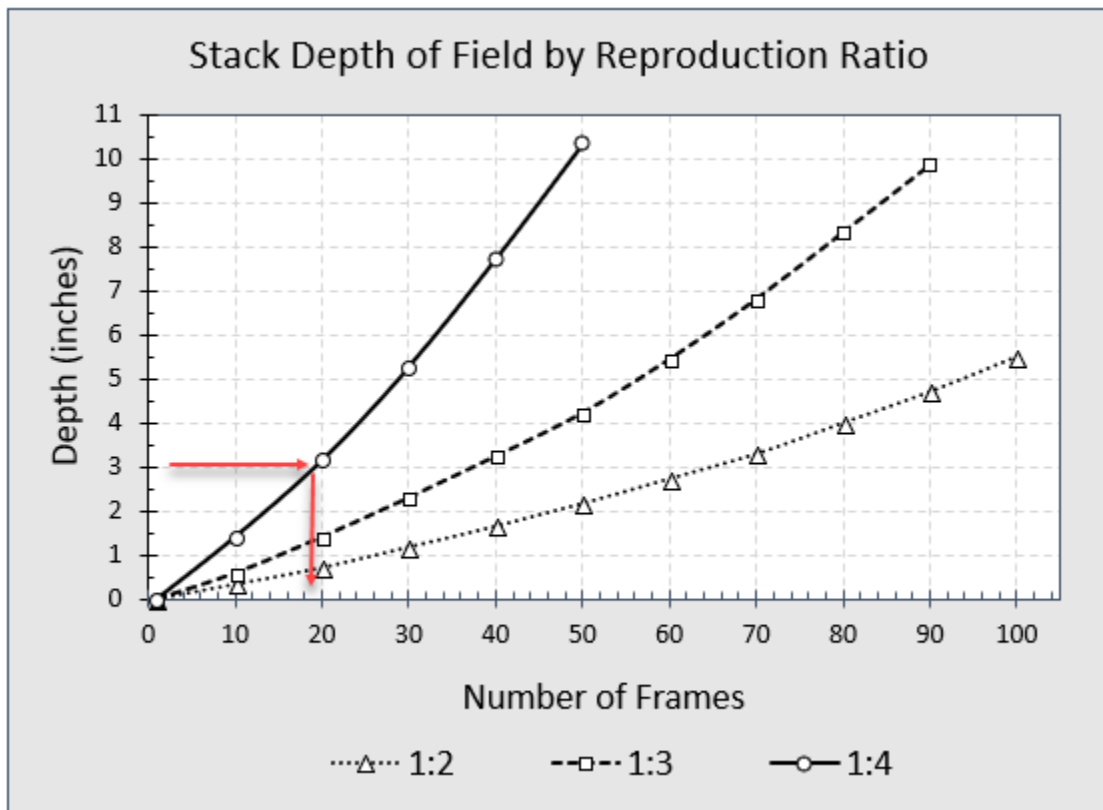
Now graph the new values as an X-Y or Scatter plot. Here's what my data looked like:



In the Field

Here's how it works in practice. Set up your camera and tripod to compose your subject as desired. Note the reproduction ratio on the lens barrel. Measure or estimate the depth of the subject that must be in focus. (I carry a tiny, key-chain tape measure to measure directly. Available in the tool section of the big box home stores ... Home Depot, Lowe's.)

Find your subject depth on the left, vertical axis, then follow horizontally to the line representing your reproduction ratio, then drop down to the horizontal axis. For example, If I needed 3" of depth at a reproduction ratio of 1:4, I would find the 3" mark on the left, move to the 1:4 curve (the first one) and read down to get about 19 frames. In practice, I would add a few CYA frames.



Here's a 'real life' example. This image made in Acadia National Park, on one of the many stone beaches. The geology is complex, with a lot of local granite and basalt; and a big dose of glacial till. There is a great range of colors and sizes. The smaller pebbles are exposed at low tide, and still wet. This really brings out the colors.

After setting up, my lens reported a reproduction ratio of 1:3. I used the focus peaking feature of Live View to get the top of the closest stone in focus. I estimated a depth of 2". The chart indicated about 28 frames; I made 30.



Conclusions

If you have a Nikon D850, Z 6 or Z 7, and use the current NIKON 105mm f/2.8 G AF-S MICRO lens, these values should work for you. Nikon has other macro lenses that you will need to test as described. You definitely need the latest AF-S type lenses, the older screw-drive lenses will not work.

Happy Stacking!

[Robert Stone Nature Photography - www.WetBootPhoto.com](http://www.WetBootPhoto.com)