Tests of Waiting Times Before Firing Niskin Bottles

During 2021-001 tests were run at 3 sites using firing times of 30s, 60s, 90s, 120s and 150s. For the deepest bottle there was no 150s firing due to there being only 24 bottles available.

The 3 sites differed in exposure to rough seas so flushing of Niskin bottles is likely moderately effective at station CCN (cast 24), good at station P25 (cast #84) and poor at station Doug26 (cast 158). It is thought that poor flushing of Niskin bottles has two effects:

1. It leads to samples from bottles containing water from lower in the water column if bottles are fired at least 10m off the bottom.
2. It leads to errors in comparisons of bottle samples with SBE salinity and dissolved oxygen. Because the SBE DO calibration drifts towards lower values, the correction will be underestimated if bottle contents come from depths with lower DO than the ambient values at the sampling depth (as is mostly the case above 800db). For salinity the opposite occurs with some bottle samples containing water from deeper in the water column with higher salinity which makes the CTD look like it is reading lower than it really is.

Salinity and dissolved oxygen were sampled at a variety of depths – deepest at P25, shallowest at CCN. COMPARE was run and the results summarized.

The comparisons are subject to many errors, including:

* Assuming local gradients are of the same sign as the large-scale gradients – this is particularly a problem with DO in shallow waters where there are often reversals.
* Slow response time in the SBE DO sensor – this is not expected to be a large error after 30s.
* Analysis and sampling errors for the bottle data. Random except for some storage errors that make bottle salinity values high. For this test storage times were not long, ranging from 1 month for the CCN cast to about 2 weeks for the Douglas Channel cast, so this error is expected to be ~0.003psu for CCN and ~0.001 for Douglas Channel.
* Slow response in the CTD data in high vertical gradients. Makes CTD DO look low.
* Mismatch between the depth of the CTD and Niskin bottle ~1m – so only a problem in high gradients. Makes CTD DO look low and CTD Salinity look high.

**SALINITY COMPARISONS**

Salinity calibration is generally judged by finding an offset that is pressure-independent.

OFFSHORE

Cast #84 – Stn P25 – Offshore waters with very noisy descent rate, many complete reversals of CTD.

There were only 2 levels at which the CTD salinity was quiet enough to put much weight on the comparison. The standard deviation in the CTD salinity was high enough between 100db and 150db that the results would not have been included in the overall cruise calibration fits.

* At 1000db the CTD varied little. Bottles varied with standard deviation of 0.0013psu which is less than the Sp value from the precision study. The differences at 30s, 90s and 120s are very close to the overall average for the primary sensors, while it was slightly higher at 60s.
* At 400s the result after 60s looked better than after 30s and varied just a little thereafter.
* At 150m the CTD was varying slightly while bottle values varied more with a standard deviation of 0.0027psu. The difference was close to the cruise average only after a wait of 150s, but the sign of the differences does not suggest a flushing problem as the bottles have lower salinity than the CTD. This is likely due to vertical displacement (Niskins being above CTD) in a very high vertical gradient.
* At 125m there appears to be a small flushing error at 30s, but by 60s the bottle values are higher than the CTD, likely because of vertical offset in the presence of a very high vertical salinity gradient. So 60s is likely the best choice.
* At 100m the result does suggest a small flushing error, with no clear pattern. The vertical gradient was low at this level.

The variations in CTD salinity during the stops together with anticipated analysis errors will account for most of the variation. When averaged over the 5 wait periods, the 30s samples are closest to the Line P average. The 30s wait was used for all those casts so that is not necessarily a good standard, but deep casts were used for the full comparison so flushing errors are expected to be small. The differences at 60s and 90s are slightly larger and even larger at 120s and 150s. But if the data from 125m are excluded there is little difference between 30s, 60s and 90s. The differences do not look to be primarily due to flushing errors. So 30s looks likely a long enough wait in most cases.

INSHORE

Cast #158 – Stn Doug26 – well protected waters. Very steady CTD descent rate.

From 100 to 350db the CTD salinity was quiet enough to be included in a normal calibration study.

* At 350db the CTD salinity was very steady. All bottles except the one after 60s suggested incomplete flushing. The 60s bottle was close to the general fit, but this may just be chance as all the differences are within 0.0023psu, so not large.
* At 250m a wait of 90s reduced what appears to be an apparent flushing error to within 0.013. Longer waits than that made little difference.
* At 150m the apparent flushing error gradually reduced with time. After 150s the difference is ‑0.0017psu which is close to the Line P fit.
* At 100m there are small apparent flushing errors that seem random. The best result was at 60s.
* At 50m the CTD data are very noisy. While there appear to be flushing errors for 30s, 60s and 90s with 90s best. Beyond that the bottle values are lower than the CTD by an amount that could easily be due to the vertical displacement. So the 120s value may be best.

The variations in CTD salinity during the stops together with anticipated analysis errors will account for some of the variation . When averaged over the 5 wait periods, the 120s samples are closest to the Line P calibration fit, but the variability is too high to conclude that is the best choice. The only case of bottle values being higher than the CTD salinity was after 120s at the level of the highest local gradient; since vertical displacement was likely significant this result looks good. Overall 120s does appear to help most.

The difference in salinity values achieved by waiting longer was 0.05psu at 50m but much lower than that at other depths.

INLET

Cast #24 – Stn CCN in Nootka Sound – somewhat protected waters. Fairly quiet CTD descent rate.

Only at 100db was the CTD salinity quiet enough to be included in a normal calibration study.

* At 100db the CTD salinity was very steady. Bottles varied with standard deviation of 0.0005psu which is less than the Sp value from the precision study. In all cases the CTD reads higher than the bottles which cannot be explained by flushing errors. The differences at 60s and 90s are the closest to the overall average from the Line P stations..
* At 75m the CTD salinity is steady while the bottle values vary a lot. A longer wait did not improve upon the 30s result. The bottle values are lower than the CTD by an amount that could be just due to the difference between CTD and bottle height.
* At 40m the CTD was steady and the 30s firing looks to be subject to a large flushing error. Longer waits led to better results but 60s or 150s looking most reliable.
* At 25m there appears to be a shed wake problem with the 30s wait. A 60s wait is a little better but not great and after than the samples are reading much lower than the CTD which could be due to very high vertical gradients.
* At 10m the CTD data are very noisy. There appear to be flushing issues but the temporal and vertical variations make this uncertain.

The variations in CTD salinity during the stops together with anticipated analysis errors will account for some of the variation . When averaged over the 5 wait periods, the 90s samples are closest to the Line P calibration fit; the 30s wait was used for all those casts so that is not necessarily a good standard, but deep casts were used where flushing errors are expected to be small. The differences at 30s and 60s suggest flushing errors but 120s and 150s have bottle salinity lower than CTD salinity which may reflect local gradients and/or temporal variation. A wait of 60s may help get samples closer to ambient conditions.

**DISSOLVED OXYGEN COMPARISONS**

Dissolved oxygen sensor calibration is generally judged by finding a straight-line fit of differences between DO sensor and bottles versus sensor DO. When there is no low DO sampling the offset is forced to be 0 and that was the case for these tests.

OFFSHORE

Cast #84 – Stn P25 – Offshore waters with very noisy descent rate, many complete reversals of CTD.

DO was >1mL/L for all samples, so fits were forced through the origin. Fits after 30s, 60s, 90s, 120s were:

CTD DO Corrected = CTD DO \* 1.0383 R2 = 0.97 (30s)

CTD DO Corrected = CTD DO \* 1.0432 R2 = 0.99 (60s)

CTD DO Corrected = CTD DO \* 1.0437 R2 = 0.98 (90s)

CTD DO Corrected = CTD DO \* 1.0443 R2 = 0.99 (120s)

As the wait increases the correction factor increases, as expected if Niskin bottles flushing improves. Examination of individual levels shows no significant change at 1000db. At 400db the 90s value looks like the best choice but the improvement is very slight and at 150db there is little variation. Where the wait looks useful is at 125db and 100db with 90s and 60s waits looking like the best choices, respectively. While a wait of 120s certainly produces good results, the improvement over a 60s wait is likely too small to justify the time. Overall, a wait of 60s looks wise from 150db up.

INSHORE

Cast #158 – Station Doug26 – well protected waters. Very steady CTD descent rate.

A similar study of inshore cast #158 shows variable results as well.

CTD DO Corrected = CTD DO \* 1.0401 R2 = 0.84 (30s)

CTD DO Corrected = CTD DO \* 1.0423 R2 = 0.91 (60s)

CTD DO Corrected = CTD DO \* 1.0441 R2 = 0.85 (90s)

CTD DO Corrected = CTD DO \* 1.0453 R2 = 0.95 (120s)

There was no improvement with a longer wait at 350db and 100db, while 90s looks ideal at 250 and 150db and at 50db a wait of 120s is best. The fact that 120s does not always lead to an improvement is likely due to variations in the ambient waters. Overall, a wait of 90s – 120s looks like the best choice above 300db.

INLET

Cast #24 – Stn CCN in Nootka Sound – somewhat protected waters. Fairly quiet CTD descent rate.

This was the only test area with extensive near-surface sampling.

The fits for cast #24 are not as tight due to being all near-surface sampling.

CTD DO Corrected = CTD DO \* 1.0345 R2 = 0.20 (30s)

CTD DO Corrected = CTD DO \* 1.0398 R2 = 0.33 (60s)

CTD DO Corrected = CTD DO \* 1.0427 R2 = 0.49 (90s)

CTD DO Corrected = CTD DO \* 1.0485 R2 = 0.64 (120s)

There was only a slight increase with wait time at 100db, while the best results at 75db and 10db was after 150s and at 40db after 120s. At 25db the best choice looks like 60s, but there was an oxygen reversal around that depth. The best fit overall was with 120s. Using the 120s fit for an SBE DO reading of 6mL/L produces a difference of 0.08mL/L from the 30s fit. This is not a large correction. However, in areas with poorer flushing, this is a warning that larger errors may be found near the surface than is apparent from the other two test areas. If accurate near-surface dissolved oxygen is required and surface waters are not well mixed a long wait may be appropriate.

CONCLUSIONS

There are too many differences between the 3 areas to expect a simple answer. But overall, longer wait times do not appear to make a significant difference below 400m. It is also of little value in very well-mixed surface waters. The wait times suggested by the study are:

* For the Nootka Sound cast a wait of 60s looks best for salinity and 120s for DO. The improvements in DO are probably not significant enough to justify more than a 60s wait.
* For the Offshore above 400m a wait of 30s to 60s looks sufficient for salinity while 60s probably improves DO enough to justify the longer wait. DO improves more with more time but probably not by enough to justify the time lost from the cruise.
* For the Douglas Channel cast a wait of 120s looks best for salinity and 90-120s for DO.

Given that extra time has a significant cost, a longer wait appears worthwhile only above 400m. This is a rough estimate and depends on vertical gradients.

For areas exposed to rough seas 60s is likely sufficient while a wait of up to 120s may be worth doing in protected waters particularly near the surface if it is not well-mixed.

Near-surface sampling was not tested extensively and the tests done suggest this may be where a longer wait is most justified.

UPDATE January 11, 2021

Several 2021 cruises tried waiting 60s above 125m and one cruise waited longer at depths chosen based on large vertical gradients noted during the downcast. There were not many salinity samples from the cases with longer waits, but dissolved oxygen sampling showed some improvement.

During the La Perouse Sept. cruise the scheme used for firing Niskin bottles was to wait 60s from 0 to 150m and 30s below that. There were some cases where there were shorter waits above 150m and some longer waits below, but the plan was mostly adhered to. As usual, it is complicated to analyze whether the effort paid off.

Most of the salinity samples above 150m came from the surface which was fairly well mixed, so we can’t be sure if improved results are due to low gradients or better flushing. Looking at the size and sign of differences may offer some evidence of whether longer waits are useful in reducing this type of error.

* 5m samples – Most differences at 5m fall close to the general fit . Cases further off suggest the samples represent conditions at 12m, 16m, 9m. One case had the bottle value lower than the CTD. The CTD had risen above the target depth and then dropped, so the sample likely represents conditions slightly higher. These differences are lower than normally seen with 30s waits, so are encouraging.
* Cast #120 – This cast had sampling at many depths. Differences from bottles varied but examination of the full profile showed bottle values found within a few metres of the bottle stop. That is an excellent result. This is likely partly due to the CTD bouncing around, thus flushing well, but the longer wait would enhance that effect.

So the salinity evidence is slight but suggests the longer waits are useful.

For dissolved oxygen there was more sampling at the relevant depths and there is a fairly flat fit through the top 150db when the cases with noisy CTD data are excluded, though that may be partly due to the fact that the criterion used to remove outliers may also remove data where flushing was poorest. The effect of incomplete flushing is to make the CTD DO appear to be reading too high. This is clearly the case in data from above 200m in a La Perouse cruise of September 2019. The 2021 data are very noisy, but nonetheless shows a more even distribution around 0 differences. This is not clear early in the cruise, perhaps because the near-surface gradients were not as large. The same criterion was used to reject outliers for both data sets. The improvement is most obvious between 100 and 150db and later in quieter waters.

There are too many variables to make a clear judgment but I think the longer waits did improve bottle data.

SeaBird recommend waiting at least 60s for all bottles, but the improvement is likely small for sampling below 150m in offshore areas. In protected waters where ship motion is low or where vertical gradients are large, it may be useful to wait 60s or longer for all bottles.

Recommendations:

For the offshore in May/June and August/September the choice of 0 to 150m is likely a good plan for both La Perouse and Line P.

For Feb. Line P the top 50 to 75m are usually well mixed, so 50-150 would be sufficient, though the 0-150m is likely more appropriate in areas other than the P stations.

For the Strait of Georgia a wait of 60s is suggested to at least 300m and is likely a good idea for all depths due to complex dissolved oxygen profiles.