

Long duration of ecological recovery from the early Toarcian extinction event in the Cleveland Basin, North Yorkshire, UK

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The Toarcian Oceanic Anoxic Event and associated early Toarcian mass extinction event (ETME) have attracted a great deal of research effort, focusing primarily on the causal mechanisms. In contrast, there is less known of the patterns of biotic recovery following this mass extinction (and others). Yet such recoveries are of interest as they record how surviving organisms radiate into newly vacated ecospace. The Cleveland Basin, North Yorkshire, has one of the most expanded Toarcian rock sections globally. Previous studies have presented a limited view of the recovery interval as the upper Toarcian sequence across much of the basin was truncated by a period of erosion during the Middle Jurassic. However, the Ravenscar coastal section preserves all of the upper Toarcian stratigraphy. In the summers of 2013 and 2017 JWA and CTSL collected 24,002 macrofossil specimens from 37 sample points covering 45 metres of the Ravenscar section, from the top of the Alum Shale Member of the Whitby Mudstone Formation to the top of the Blea Wyke Sandstone Formation. The samples included benthic taxa (principally bivalves and gastropods, with smaller number of brachiopods, echinoderms, serpulids, scaphopods, crustaceans and bryozoans) and nektonic taxa (belemnites and ammonites). These allowed us to construct new range data, and allowed us a full evaluation of the biotic recovery from the ETME. Ecological tiering was the first to respond to the amelioration of conditions in the *Bifrons* Zone, approximately 1.75-2.71 million years following the extinction event. Many of the ecological groups that disappeared across the extinction interval began to reappear, although often represented by only a single species. Benthic species richness and ecological diversity subsequently dropped in the *Variabilis* and *Thoarsense* Zones, and then both increased substantially in the *Levesquei* Zone, coincident with the onset of sandy facies deposition in the basin, 5.1-6.89 million years after the extinction event. It was only then that species and ecological diversity regained their pre-extinction late Pliensbachian to *Tenuicostatum* Zone values. This surprisingly protracted recovery interval may have been caused by persistent environmental stress and/or sea-level change.

Some of the benthic taxa appearing in the late Toarcian *Levesquei* Zone into the Cleveland Basin are typical of Middle Jurassic faunas. Future work will be to ascertain from where these immigrants came. This will present taxonomic challenges that require whole-community collaboration.