Calcium carbonates (CaCO₃) often accumulate in mangrove and seagrass sediments. As CaCO₃ production emits CO₂, there is concern that this may partially offset the role of Blue Carbon ecosystems as CO₂ sinks through the burial of organic carbon (Corg). A global collection of data on inorganic carbon burial rates (Cinorg, 12% of CaCO₃ mass) revealed global rates of 0.8 TgCinorg yr⁻¹ and 15–62 TgCinorg yr⁻¹ in mangrove and seagrass ecosystems, respectively. In seagrass, CaCO₃ burial may correspond to an offset of 30% of the net CO₂ sequestration. However, a mass balance assessment highlights that the Cinorg burial is mainly supported by inputs from adjacent ecosystems rather than by local calcification, and that Blue Carbon ecosystems are sites of net CaCO₃ dissolution. Hence, CaCO₃ burial in Blue Carbon ecosystems contribute to seabed elevation and therefore buffers sea-level rise, without undermining their role as CO₂ sinks.
Mangrove forests and seagrass meadows have the capacity to elevate the seabed through the accretion of inorganic and organic particles at global rates of ~0.5 and ~0.2 cm yr\(^{-1}\), respectively\(^1\). Sediment accretion in mangrove forests and seagrass meadows leads to the sequestration of organic carbon (C\(_{\text{org}}\))\(^3,\)\(^{13}\) originating from within and outside of the vegetated ecosystem\(^4\). Although mangroves and seagrass ecosystems occupy only a small fraction of the total coastal area (<2%), they contribute 10% and 25% to the yearly C\(_{\text{org}}\) sequestration in the coastal zone\(^5,\)\(^6\), respectively. Recognition of mangrove and seagrass meadows, together with saltmarshes, as sites of intense C\(_{\text{org}}\) burial led to the formulation of Blue Carbon strategies to mitigate and adapt to climate change, through conservation and restoration of these ecosystems\(^7\)\(^-\)\(^9\). The focus on Blue Carbon has provided substantial impetus to assess sediment C\(_{\text{org}}\) concentrations and burial rates in vegetated coastal ecosystems, which recently have been widely reviewed\(^9\).

C\(_{\text{org}}\) generally represents a minor fraction (2–3%) of buried material within mangrove and seagrass sediments\(^1\)\(^0\)\(^-\)\(^11\) (although this is highly variable\(^2\)). The rest being siliciclastic and carbonate particles. A global assessment of the concentration of inorganic carbon concluded that C\(_{\text{inorg}}\) can exceed C\(_{\text{org}}\) concentration in seagrass sediments\(^1\)\(^3\). Seagrass and mangrove plants do not calcify per se; however, they provide habitats for an abundant associated calcifying fauna and flora (e.g., crabs, sea stars, snails, bivalves, calcified algae, foraminifera), whose shells and skeletons may be deposited and buried in the sediment along with the plant litter, and the organic and inorganic particles imported from adjacent ecosystems.

Counterintuitively, CaCO\(_3\) production represents a source of CO\(_2\) to the atmosphere, as calcification produces CO\(_2\) with a ratio of ~0.6 mol of CO\(_2\) emitted per mol of CaCO\(_3\) precipitated\(^1\)\(^4\). This has led to the argument that high CaCO\(_3\) burial may partially offset CO\(_2\) sequestration associated with C\(_{\text{org}}\) burial in some seagrass meadows and mangrove forests\(^1\)\(^5\). However, there are several caveats that affect these arguments and render inferences on the role of Blue Carbon ecosystems as net CO\(_2\) sinks or sources inconclusive\(^1\)\(^3\),\(^1\)\(^6\), based on the comparison of C\(_{\text{org}}\) and C\(_{\text{inorg}}\) sediment burial rates. To date, very few articles report the burial rates of CaCO\(_3\) in mangrove and seagrass ecosystems\(^1\)\(^5\)\(^-\)\(^7\), and the role of C\(_{\text{CaCO3}}\) burial in sediments and CO\(_2\) emissions depends on the balance between dissolution and production. If CaCO\(_3\) dissolution equals local calcification, then the burial of CaCO\(_3\) is supported exclusively by allochthonous inputs and is neutral in terms of CO\(_2\) emissions or sequestration. If dissolution exceeds local calcification, then CaCO\(_3\) dynamics add to the CO\(_2\) sink capacity of Blue Carbon ecosystems, even if CaCO\(_3\), which must be subsidized from allochthonous sources, is buried in the sediments. Only if CaCO\(_3\) dissolution is lower than local calcification does CaCO\(_3\) burial result in CO\(_2\) emissions.

Here we address the current gap in global estimates of C\(_{\text{inorg}}\) burial in seagrass and mangrove ecosystems by providing first estimates of contemporary (last century) C\(_{\text{inorg}}\) burial rates. We rely on a compilation and analysis of data on sediment chronologies (i.e., including radiometric dating of sediment cores with \(^{210}\)Pb) and C\(_{\text{inorg}}\) concentrations from around the world (Fig. 1). We compare burial, calcification and dissolution rates in three locations where most of the carbon mass balance terms were available. We then address the role of CaCO\(_3\) burial in CO\(_2\) emissions by resolving the source of the CaCO\(_3\) buried in seagrass meadows as either allochthonous or autochthonous (i.e., from associated flora and fauna). We conclude that the high amounts of CaCO\(_3\) found in Blue Carbon sediments can not be converted into CO\(_2\) emissions.

Results

Global disparities in Blue Carbon sediments. CaCO\(_3\) supports an important part of sediment accretion rates (SARs) in seagrass ecosystems, although with large geographical disparities and a non-normal distribution (Shapiro–Wilk test, \(p < 0.001\)). Indeed, in 40% of global locations, the CaCO\(_3\) concentration was under 10% dry weight (DW), whereas in 28% of locations the CaCO\(_3\) content exceeded 80 %DW (see Supplementary Figure 1a). Overall, the median (interquartile range: IQR) global concentration of CaCO\(_3\) in seagrass meadow sediments was 61 (56) %DW (mean ± SE of 54 ± 7).

In mangrove forests, we observe a large difference between the mean (± SE) and the median (IQR) CaCO\(_3\) concentration: 21 ± 11% and 3 (31)%, respectively. This is explained by the strong non-normal distribution between the eight study locations examined, including a group of five locations with < 5 %DW CaCO\(_3\) in their sediments and three locations with CaCO\(_3\) contents between 20 and 75 %DW (Shapiro–Wilk test, \(p < 0.001\), see Supplementary Fig. 1b). Converted into C\(_{\text{inorg}}\) concentrations (after normalization for the sediment bulk density), we obtain median (IQR) C\(_{\text{inorg}}\) concentrations in seagrass and mangrove sediments of 59 (66) and 1 (21) mgC\(_{\text{inorg}}\) cm\(^{-3}\), respectively (means ± SE of 63 ± 11 and 35 ± 17 mgC\(_{\text{inorg}}\) cm\(^{-3}\)) (Fig. 2a).

Using the median SARs in seagrass and mangrove ecosystems compiled in this study (0.22 and 0.23 cm yr\(^{-1}\) respectively; Fig. 2b), we estimate median (IQR) C\(_{\text{inorg}}\) burial rates in seagrass and mangrove ecosystems of 87 (154) and 6 (207) gC\(_{\text{inorg}}\) m\(^{-2}\) yr\(^{-1}\), respectively (means ± SE of 182 ± 94 and 90 ± 43 gC\(_{\text{inorg}}\) m\(^{-2}\) yr\(^{-1}\)) (Fig. 2c, Fig. 3). These values correspond to vertical accretion rates of CaCO\(_3\) of the order of 0.1 and 0.001 cm yr\(^{-1}\) in seagrass and mangrove ecosystems, respectively. Our mean SAR values agree with previously reported global values\(^1\)\(^3\). However, our new estimates of burial rates are lower than the previous, indirect median estimate of C\(_{\text{inorg}}\) burial rate of 108 gC\(_{\text{inorg}}\) m\(^{-2}\) yr\(^{-1}\) (mean ± SE of 126 ± 31 gC\(_{\text{inorg}}\) m\(^{-2}\) yr\(^{-1}\)) reported by Mazzarras et al.\(^1\)\(^3\).

Global annual burial rates of C\(_{\text{inorg}}\). Scaling up to the global seagrass coverage (150,000–600,000 km\(^2\))\(^7\), the annual burial rate of C\(_{\text{inorg}}\) ranged from 13 to 52 TgC\(_{\text{inorg}}\) yr\(^{-1}\) for the twentieth century (Table 1). Partitioning between tropical and non-tropical seagrass meadows as in Mazzarras et al.\(^1\)\(^3\) showed that 90% of the global C\(_{\text{inorg}}\) burial occurs in the tropics (Table 1). In seagrass meadows, our estimates of global burial of C\(_{\text{inorg}}\) are equivalent to 31–55% of the available estimates of contemporary C\(_{\text{org}}\) burial rates (48–112 TgC\(_{\text{org}}\) yr\(^{-1}\))\(^1\)\(^7\), depending on the estimated global seagrass coverage considered. If all buried CaCO\(_3\) is locally produced (i.e., of autochthonous origin), the burial rates of C\(_{\text{inorg}}\) in seagrass meadows would represent emissions of 8–37 TgC yr\(^{-1}\) to the atmosphere and thus would offset their role as CO\(_2\) sinks through the sequestration of C\(_{\text{org}}\) by ~17–33%.

The extent of global mangrove coverage yields a median burial rate of 0.8 TgC\(_{\text{inorg}}\) yr\(^{-1}\) (mean of 13 TgC\(_{\text{inorg}}\) yr\(^{-1}\)) (Table 1). This value should be considered as a first-order estimate because of the scarcity of data available on C\(_{\text{inorg}}\) burial rates in mangroves and because of the non-normal distribution between CaCO\(_3\)-rich and CaCO\(_3\)-poor mangrove sediments (Supplementary Figure 1b). When comparing with the global C\(_{\text{org}}\) burial rates estimate of 31 TgC\(_{\text{org}}\) yr\(^{-1}\)\(^3\), the median C\(_{\text{inorg}}\) burial rates would correspond to a negligible reduction of net atmospheric CO\(_2\) uptake. However, assuming that all sedimentary CaCO\(_3\) was produced in situ, the C\(_{\text{inorg}}\) burial rates can largely outweigh C\(_{\text{org}}\) burial in CaCO\(_3\)-rich mangroves. For example, the C\(_{\text{inorg}}\) burial rate corresponds to 10–20 times the C\(_{\text{org}}\) burial rate in the Arabian Peninsula\(^1\)\(^7\)-\(^1\)\(^9\).
Discussion

CaCO3 burial in Blue Carbon ecosystems is the balance between inputs (autochthonous and allochthonous) and losses (dissolution and export). Assessments of the mass balance of CaCO3 in seagrass meadows are few and none have been reported, to our knowledge, in mangrove forests. For seagrass ecosystems, we assessed the balance between calcification, dissolution and burial of CaCO3 in three locations: the Balearic Islands, Spain20,21, Shark Bay in Western Australia22 and Florida Bay, USA23,24 (Table 2).

The most comprehensive assessment of seagrass carbon budgets is that reported for a Mediterranean Posidonia oceanica meadow at Magalluf (Mallorca Island, Spain)20,21,25,26. In this meadow, Barrón et al.21 estimated a net CO2 uptake by primary production of 8.4 gC m−2 yr−1. This estimate was corroborated by the Corg burial rate, estimated independently, at 9 ± 2 gCorg m−2 yr−127. Barrón et al.21 also estimated net calcification rates of 51 gCaCO3 m−2 yr−1, corresponding to 6 gCinorg m−2 yr−1. This amount of calcification would result in a CO2 emission of 3.6 gC m−2 yr−1 (0.6-fold the net calcification14). The CO2 emission by calcification therefore represents an offset of 40% of the CO2 uptake from net primary production (thereby yielding a total CO2 sequestration of 4.8 gC m−2 yr−121). However, the Cinorg burial rate in this meadow is estimated here at 226 gCinorg m−2 yr−1. This is two orders of magnitude greater than the net calcification rate of 6 gCinorg m−2 yr−121) (Table 2). This implies that about 90% of the CaCO3 burial in this seagrass meadow must be supported by allochthonous inputs. Therefore, calculation of the CO2 sequestration by comparing Cinorg and Corg burial rates or stocks would have concluded that this meadow is a strong source of CO2, whereas estimates of calcification rates and net primary production concludes that it is a sink (as confirmed independently through air–sea flux measurements26).

Similarly, in Shark Bay, the burial of Cinorg is four times higher than the independently reported net calcification rate22 (Table 2). This again could require large allochthonous carbonate inputs.

In Florida Bay, the low ratio between Corg and Cinorg concentration in the sediment (g cm−3) implied that seagrass meadows may be a net source of CO2 to the atmosphere15. However, such assessment requires consideration of the full carbon mass balance, including accounting for allochthonous inorganic carbon inputs and the balance between calcification and dissolution in the meadows. The contemporary Cinorg burial rates in Florida Bay are approximately ninefold higher than the global median, whereas median SAR is about fourfold higher than estimated globally, in an area where 80% of the sediment dry mass is composed of CaCO3. However, attempts to assess the gross or net calcification rates in the area yielded values one and two orders of magnitude lower than the estimated CaCO3 burial rates (Table 2)23,24. In contrast, past geological work in the Bay has suggested that it is a net producer of CaCO328. It is likely to be that some areas within this large Bay act as sources of CaCO3 and some others as sinks, helping explain the discrepancy between reported production and burial estimates. Hence, internal redistribution of CaCO3 production within Florida Bay needs to be considered when drawing inferences on the role of seagrass meadows from sediment composition.

These three example locations are in areas close to coral reefs and/or terrestrial lithogenic sources of CaCO3. We could not find estimates of calcification rates (net or gross) in areas without external sources of CaCO3. The discrepancies between calcification rates and burial rates in the three example locations could indicate that an important fraction of CaCO3 burial (> 90%) is supported by CaCO3 produced elsewhere and trapped in the seagrass sediments. This conclusion is consistent with

Fig. 1 World map of sediment cores locations. Brown circles: mangrove cores locations; blue: seagrass cores locations; yellow: seagrass cores non-dated but with inorganic carbon content measured13.
comparable $C_{inorg}$ concentrations within and outside seagrass meadows, whereas, in contrast, $C_{org}$ concentrations are higher in seagrass sediments$^{13}$. A large role of $C_{inorg}$ import is also consistent with the large CaCO$_3$ export from coral reefs to adjacent waters, equivalent to 25–50% of the CaCO$_3$ production, predominantly to reef lagoons$^{27}$, where seagrass meadows and mangroves often grow. Mangroves, seagrass and saltmarsh ecosystems are likely to be sites of net carbonate dissolution. Roots of marine plants release organic compounds and oxygenate the sediments during the day, promoting microbial aerobic remineralization of organic matter, thereby increasing sedimentary respiratory CO$_2$$^{28,30}$ and/or stimulating the re-oxidation of reduced metabolites. These processes result in the release of strong acids (e.g., H$_2$SO$_4$, HNO$_3$)$^{31-33}$, which leads to CaCO$_3$ dissolution in the sediment$^{34,35}$ (although re-precipitation can occur$^{34}$).

**Fig. 2** Sediment cores data. 

**a** Inorganic carbon ($C_{inorg}$) concentration, 

**b** sediment accumulation rates (SAR), and 

**c** $C_{inorg}$ burial rates. The x represents the mean. Bars are the first and last quartile.

**Fig. 3** Inorganic carbon burial rates in all locations. Mean $C_{inorg}$ burial rates in all locations in sediment cores for seagrass meadows and mangrove forests, organized from low to high latitudes. Bars are the SE. Labels are the number of cores per location.

| Table 1 Median (mean) global $C_{inorg}$ burial rates for seagrass meadows and mangrove forests considering one, and, for seagrass, two world regions (tropical and higher latitudes) |
|--------------------------------------------------|-----------------|---------------------|---------------------|-----------------|
| Burial rate, ($TgC_{inorg}$ yr$^{-1}$)             | Global          | Tropical            | Higher lat.         | Sum             |
| Seagrass This study                                | 13(27)–52(109)  | 14(41)–57(163)      | 1(3)–5(14)          | 15(43)–62(177)  |
| Mangrove This study                                | 19(28)–65(79)   |                     |                     |                 |
| Mazarassa et al$^{13}$                             |                 |                     |                     |                 |
Dissolution of CaCO$_3$ might also be influenced by the CO$_2$ system in the water column of Blue Carbon ecosystems. Respiration and photosynthesis of the flora and fauna, together with sediment redox processes in seagrass and mangrove ecosystems, strongly influence the chemistry of the water column, generating large diel amplitudes of the saturation state for CaCO$_3$ (Ω) with a tendency towards dissolution or the reduction of calcification at nighttime, amplified at low tide$^{36-40}$. The dissolution of allochthonous CaCO$_3$ in carbonate platform areas, caused directly or indirectly by metabolism of the marine vegetation and associated biota, leads to a reduction in pCO$_2$ through the release of fossilized total alkalinity. This sink of atmospheric CO$_2$ should be incorporated into the Blue Carbon framework. A recent assessment considers alkalinity addition through the dissolution of allochthonous carbonate as a very effective geo-engineering approach to remove atmospheric CO$_2$ and mitigate climate change$^{41,42}$.

Similarly, saltmarshes are not known to host high levels of calcifying organisms but can accumulate CaCO$_3$ from allochthonous sources. In arid tropical saltmarshes of the Western Arabian Gulf, dominated by succulent shrubs, a concentration of CaCO$_3$ of 57 ± 8% in sediments and a contemporary burial rate of C$_{inorg}$ of 100 ± 15 gC$_{inorg}$ m$^{-2}$ yr$^{-1}$ (mean ± SE) were found$^{43}$. In a temperate saltmarsh of the Western Scheldt estuary in the Netherlands, a concentration of CaCO$_3$ of 14 ± 1% and a high contemporary burial rate of 467 ± 99 gC$_{inorg}$ m$^{-2}$ yr$^{-1}$, mostly due to high SAR (1.1 + 0.3 cm yr$^{-1}$), were measured$^{44}$. Yet, this does not imply that CaCO$_3$ dynamics have a negligible role in saltmarsh carbon budgets, as they may still act as sites of net dissolution of CaCO$_3$, adding to the removal of CO$_2$ associated with C$_{org}$ burial. A dissolution rate of 24–96 gC$_{inorg}$ m$^{-2}$ yr$^{-1}$ was estimated in the sediment of the saltmarshes of the Eastern Scheldt estuary, corresponding to ~85% of the C$_{inorg}$ burial rate$^{44}$.

To further examine the conclusion that Blue Carbon ecosystems are sites of substantial allochthonous CaCO$_3$ deposition, based on existing mass balances for Blue Carbon sediments, we examined (qualitatively) the relationship between the CaCO$_3$ % DW in sediments and the presence/absence of sources of CaCO$_3$ adjacent to the coring locations, including coral reefs and terrestrial lithogenic sources of CaCO$_3$ (Fig. 3, see dataset in Supplementary Information). Seagrass and mangrove ecosystems without potentially large adjacent allochthonous CaCO$_3$ sources have a remarkably lower median (IQR) sediment CaCO$_3$ content of 4 (15) and 1 (1) %DW (means ± SE of 11 ± 4 and 1.7 ± 0.8 % DW), respectively, compared with 59 (51) and 61 (27) %DW (means ± SE of 56 ± 5 and 53 ± 16 %DW) when at least one allochthonous CaCO$_3$ source was present (Fig. 3). For sediments in seagrass meadows, the presence of coral reefs (t-value = 4.68, df = 48.5, p < 0.0001) and lithogenic sources (t-value = 4.76, df = 57.3, p < 0.0001) increased the amount of CaCO$_3$ in the sediment. However, there was a significant interaction between these factors (t-value = −3.29, df = 53.2, p = 0.0018), because the CaCO$_3$ % DW in the presence of both allochthonous sources was less than would be expected if these variables were additive. The presence/absence of coral reefs and lithogenic sources accounted for 36% of the variation in CaCO$_3$, whereas the random variables (study, lithology grouping and marine province) accounted for 54% of the variation in CaCO$_3$ (see Methods for model description). Mangrove sediment samples showed a similar pattern to the seagrass meadows and the presence of allochthonous sources had a marginally significant positive effect on the amount of CaCO$_3$ in the sediment (t-value = 4.29, df = 1.81, p = 0.0596). The presence/absence of a CaCO$_3$ source accounted for 71% of the variation in CaCO$_3$ within mangrove sediments, whereas the random variables accounted for 20% of the variation in CaCO$_3$.

In testing for biases of outlying cores and studies, we found that one study from Western Florida had an outlying data point that disproportionality skewed the results. The study from Western Florida had relatively low CaCO$_3$ but did have an allochthonous source of CaCO$_3$. When this study was removed from the analysis, the presence of an allochthonous source became significant (t-value = 7.92, df = 4.16, p = 0.0012). This highlights the need for more studies in mangrove sediments to determine the global influence of allochthonous sources on CaCO$_3$ content.

In seagrass meadows, the median (IQR) C$_{inorg}$ burial rate found in areas where no allochthonous sources were identified was 1 (13) gC$_{inorg}$ m$^{-2}$ yr$^{-1}$ (mean ± SE of 8 ± 4), only 1.1% of the global median. This contrast is consistent with our hypothesis that much of the C$_{inorg}$ buried in seagrass and mangrove sediments is allochthonous. It explains the non-normal distribution of CaCO$_3$ concentrations observed in sediments of seagrass and mangroves (Supplementary Figure 1), and indicates that the import of CaCO$_3$ from carbonate-forming ecosystems or adjacent karstic areas is the norm$^{37}$. The global burial rate of C$_{inorg}$ in seagrass meadows is between a third to a half of their C$_{org}$ burial rate$^{1-7}$, whereas for mangroves our first estimate of global C$_{inorg}$ burial rates is only 3% of the C$_{org}$ burial rate$^{5}$. If the buried CaCO$_3$ and C$_{org}$ in seagrass sediments were produced entirely in situ, C$_{inorg}$ burial would offset up to a third of CO$_2$ sequestration through C$_{org}$ burial, particularly in tropical seagrass ecosystems where ~90% of the global C$_{inorg}$ burial occurs. However, imbalances between production, dissolution and burial, and the observation of much higher CaCO$_3$ concentrations in sediments near lithogenic formations and coral reefs, suggest that, where present, allochthonous CaCO$_3$ inputs are substantial and support most of the net CaCO$_3$ burial.

Locally, despite supporting significant CaCO$_3$ burial, Blue Carbon ecosystems may be sites where imported CaCO$_3$ dissolves, strengthening rather than weakening the capacity of these ecosystems to sequester CO$_2$. Whereas there is emphasis on apportioning the sources of autochthonous and allochthonous C$_{org}$ in Blue Carbon sediments (up to 50% of the buried C$_{org}$)$^{13,19}$, determining the sources of CaCO$_3$ in Blue Carbon sediments is just as important, to resolve the role of vegetated coastal

**Table 2 Burial rates of CaCO$_3$ compared to calcification rates in seagrass ecosystems**

| Sediment | Community production rate of CaCO$_3$ | Community net calcification rate | Sediment | Community production rate of CaCO$_3$ | Community net calcification rate | Sediment | Community production rate of CaCO$_3$ | Community net calcification rate |
|----------|--------------------------------------|----------------------------------|----------|--------------------------------------|----------------------------------|----------|--------------------------------------|----------------------------------|
|          | gCaCO$_3$ m$^{-2}$ yr$^{-1}$          | gC$_{inorg}$ m$^{-2}$ yr$^{-1}$   |          | gCaCO$_3$ m$^{-2}$ yr$^{-1}$          | gC$_{inorg}$ m$^{-2}$ yr$^{-1}$   |          | gCaCO$_3$ m$^{-2}$ yr$^{-1}$          | gC$_{inorg}$ m$^{-2}$ yr$^{-1}$   |
| Florida Bay, USA | 626$^{33,24}$ | 80 | 18$^{40}$ | 2.2 | 82 ± 2 | 4792 ± 756 | 756 ± 91 |          |
| Balearic Islands, Spain | 68$^{20}$ | 8 | 51$^{3}$ | 6 | 81 ± 3 | 1866 ± 214 | 226 ± 30 |          |
| West Shark Bay, Australia | 375 ± 62$^{22}$ | 45 ± 7 | 295$^{22}$ | 35 | 60 ± 5 | 1240 ± 232 | 149 ± 30 |          |

Comparison between seagrass-associated community production rate of carbonate (obtained from standing stock assessments and leaves or calcification turnover rates) and community net calcification rates (balance between calcification and dissolution, calculated from variations of total alkalinity) from the literature, and carbonate burial rate in three locations with carbonate-rich sediments.
ecosystems as CO₂ sinks and, hence, their potential to support climate change mitigation. The current focus on C_{org} budgets in vegetated coastal ecosystems needs to be augmented with integrative assessments of organic and inorganic carbon fluxes and budgets, including both allochthonous and autochthonous inputs. Moreover, these assessments must consider the sources and fate of carbon exchanged between Blue Carbon and adjacent ecosystems, as Blue Carbon ecosystems export important amounts of their organic production but also import significant amounts of CaCO₃ and organic matter from adjacent sources. A comparison of paired vegetated and unvegetated sediment CaCO₃ % DW showed that vegetated and adjacent unvegetated sediments have similar carbonate concentrations, both using standard parametric statistics (general linear model (GLM), t-value = 1.32, df = 83.1, p = 0.191) and meta-analysis (z-value = 0.88, p = 0.379; Supplementary Fig. 2A,B), which also showed no evidence for reporting bias (all points within the 95% confidence lines of the funnel plot, Supplementary Fig. 2C). This provides further support to the hypothesis that much of the carbon buried in vegetated coastal sediments derives from allochthonous sources rather than being produced within the habitat.

Inorganic carbon burial in Blue Carbon ecosystems has been overlooked, with the rates compiled here representing the first direct estimates reported in the literature. These estimates confirm that seagrass ecosystems, and to lesser extent mangrove ecosystems, are intense sites of CaCO₃ burial, supporting sediment accretion. CaCO₃ burial is a fundamental process supporting the role of Blue Carbon ecosystems in climate change adaptation, which is underpinned by their capacity to rapidly accrete sediments, reducing relative SLR by raising the seafloor.

Methods

Calculation of the C_{org} accretion rate. We searched the peer-reviewed literature for data on sediment cores dated with ²¹⁰Pb, including CaCO₃ or C_{org} concentration in seagrass and mangrove sediments. Search terms on Google Scholar were seagrass OR mangrove AND ²¹⁰Pb OR SAR OR sediment accretion rate. We then searched returned articles that contained data on SAR and CaCO₃ or C_{org} data. We found only one study presenting CaCO₃ content in a dated sediment core. However, we found 15 and 22 studies with SAR for seagrass and mangrove sediments, respectively. To obtain the CaCO₃ or C_{org} concentrations needed to calculate C_{org} burial rates, we used the database of Mazzarasa et al.13, which was the most recent exhaustive compilation of sediment cores from Blue Carbon habitats, for data on CaCO₃ in seagrass sediments. We also contacted experts in Blue Carbon studies (published studies using cores from Blue Carbon habitats) for unpublished CaCO₃ sediment concentration data (see data and references in Supplementary Data 1). In total, we compiled 42 and 53 ²¹⁰Pb dated cores with CaCO₃ content in mangrove and seagrass ecosystems, respectively (see PRISMA checklist and flow diagram in Supplementary Note 1).

The SARs (cm yr⁻¹) from the literature were re-calculated according to the constant flux–constant sedimentation model9, to have a coherent and comparable dating system between all cores. The CaCO₃ concentration (% sediment DW) was calculated as the mean between all slices younger than 1900, for cores with the contemporary ²¹⁰Pb chronologies. The C_{org} concentration in sediment (gC_{org} m⁻³) was calculated from the dry bulk density (g m⁻³) and the percentage of CaCO₃ content (using sediment DW), considering a mass ratio of 12% carbon in CaCO₃. The C_{org} burial rate (gC_{org} m⁻² yr⁻¹) was then calculated as the product of the SAR and the C_{org} concentration for each sediment core. Cores with negligible content of CaCO₃ were also included in the calculation (see Supplementary Figure 1).

All cores from the same site or area and with similar presence or absence of allochthonous sources of CaCO₃ (see below) were treated as replicates for a global location and averaged for the analysis (geologic grouping). For seagrass, the 51 cores dated with ²¹⁰Pb were grouped into 17 locations (Figs. 2, 3). For mangroves, we compiled a total of 42 cores dated with ²¹⁰Pb in 8 locations (Figs. 2, 3). Seagrass locations ranged from tropical to sub-arctic locations, with 50% of estimates derived from tropical and subtropical locations and 50% from higher latitudes. Mangrove sediment derived mostly from subtropical locations (seven out of eight locations), particularly in Australia and the Arabian Peninsula (Supplementary Figure 2).
burial rate or CaCO3 %DW were normally distributed (all \( p < 0.05 \)). We therefore chose to use the median (IQR) as the most appropriate description of central tendency. Traditional meta-analysis tools, which calculate effect sizes to standardize the difference between control and experimental treatments, thereby allowing comparison among disparate response variables and weighting to account for unequal variance among studies, could not be used for this analysis for multiple reasons. These reasons include that the question posed and the studies available did not include experimental designs with paired control and experimental plots required for effect size calculations, that there was a single response variable facilitating direct comparison and data integration, and, most importantly, that we used the raw data for each core. Instead, we ran a statistical test using a mixed effect GLM to determine the effect of coral reefs and lithogenic sources on the CaCO3 %DW of the sediment. For sediments within seagrass meadows, the GLM included two fixed factors (presence/absence of coral reefs and of lithogenic sources), as well as the interaction between the two factors. For sediment within mangrove forests, the GLM included one fixed factor (presence/absence of allochthonous sources), because replication did not exist for all combinations of the two factors. The data had unequal samples among studies and studies were not evenly distributed around the globe (Fig. 1), which could result in pseudo-replication and biased results. To account for the data structure and minimize non-independence, we included three separate random variables, which included study, lithology grouping and marine province. The marine province was determined for each sample location using the marine provinces of the world as defined by Spalding et al.53. Separate pools where run for seagrass and mangrove sites. The statistical model was produced using the lmertest function within the lme4 package54 and \( p \)-values were calculated with the lmerTest package55. The \( R^2 \) was calculated for the fixed and random effects using the \textit{rsquared} GLMM function in the MuMIn package56. The response variable was log transformed, which improved the model fit compared with raw data. The model fit was assessed by plotting the \( Q \)-\( Q \) plot (linear relationship) and the fitted values compared with the residuals (random distribution). To test whether individual cores or studies were biased and having a disproportionate influence on findings, we systematically removed any studies that contained outlying samples as determined from being outside the 95% confidence interval for the fitted values vs. residuals comparison using the plot model function from sjPlot package57. This analysis was conducted in R version 3.4.2.

Reporting bias and its effect on findings is an important consideration for meta-analyses58 and when the result from a meta-analysis is not the same as it would have been if data from all correctly conducted studies were included in the analysis59. A main cause of reporting bias is not publishing research because of a lack of merit as determined by the researcher, reviewer or editor60. As indicated by the data inclusion flow diagram (Supplementary Fig. 3), researchers often measured but did not publish data on soil CaCO3 content and authors needed to be directly contacted for these results. In addition, the researchers not only provided information from published studies but also unpublished data on CaCO3 content (10 of 51 seagrass studies included in the analysis were not published). For these reasons, it is unlikely to be that our findings were affected by reporting bias. A subset of data collection for this study included the appropriate information to run both a GLM and a traditional meta-analysis (effect size could be calculated between paired data). The data included information from nine studies that measured the CaCO3 content of sediment from both vegetated and unvegetated habitats. There were 92 core samples with 32 from unvegetated and 60 from vegetated habitats (Supplementary Fig. 2A). The GLM followed the same procedures as detailed in the main text, except it had only two randomly factor (study and marine province), because study and lithology grouping differed in only one instance. For the meta-analysis, the data were paired for each study and the mean CaCO3 %DW, number of samples and SD were calculated for vegetated and unvegetated cores for each study. Two studies included in the GLM were removed for the meta-analysis, because they only had one core for an unvegetated habitat and SD could not be calculated, leaving seven comparisons for this analysis. Hedges’ \( g \) was calculated for the effect size following Borenstein et al.60 (Eqs. 1–3) and a variance for each effect size was also calculated (\( V_g \))(Eq. 4), as indicated by equations:

\[
Hedges’ \ g = \frac{(X_1 - X_2) \cdot \sqrt{3}}{SD_{pooled}} \tag{1}
\]

\[
SD_{pooled} = \sqrt{\frac{(n_1 - 1)SD_1^2 + (n_2 - 1)SD_2^2 + n_1 + n_2 - 2}{n_1 + n_2 - 2}} \tag{2}
\]

\[
f = 1 - \frac{3}{4(n_1 + n_2 - 2) - 1} \tag{3}
\]

\[
V_g = \frac{n_1 + n_2}{n_1 \cdot n_2} + \frac{g^2}{2(n_1 + n_2)} \tag{4}
\]

\( X_1 \) and \( X_2 \) are the mean (\( \mu \) is sample size) of vegetated and unvegetated sediments, along with \( SD_{pooled} \) and \( f \), which accounts for biases associated with different sample sizes. The meta-analysis included the same two random variables as the GLM and was conducted using the \texttt{rma.mv} function from the \texttt{metafor} package61. This analysis was conducted in R version 3.4.2.

The global annual burial of inorganic carbon (\( \text{Tg}_{\text{CaCO3 yr}^{-1}} \)) in seagrass meadows was calculated as the product of the median burial rates and the estimated global seagrass area, which ranges from 150,000 to 600,000 km\(^2\). We also calculated the global annual burial of \( \text{CaCO3} \) as the sum of separate calculations for tropical and arid climates and meadows at higher latitude climates. Median \( \text{CaCO3} \) burial rates were calculated for tropical (core locations with tropical and hot desert climates) and non-tropical areas (temperate, continental and polar climates) and multiplied by the global seagrass cover range under the assumption that 2/3 of the seagrass area is in the tropical and subtropical zone. The global annual burial of inorganic carbon (\( \text{Tg}_{\text{CaCO3 yr}^{-1}} \)) in mangroves was calculated as the product of the global median \( \text{CaCO3} \) burial rates and the estimated global mangrove cover of 137,760 km\(^2\).

### Data availability

The dataset is available as Supplementary Data 1.

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Author contributions

C.M.D. and V.S. conceived and designed this work. V.S. wrote the manuscript with support from N.R.G., P.I.M., D.T.M., J.M., O.S. and C.M.D. V.S., N.R.G., P.I.M., D.T.M., J.M., O.S., H.A., A.A.-O., M.C., N.M., P.I.M., M.A.M., K.J.M.G., M.P.O., C.I.S., I.R.S., J.M.S., T.T., K.W. and C.M.D. contributed data and quality check was done by A.A.-O. and P.M. Analysis of data was performed by V.S. and N.R.G. V.S., N.R.G., P.I.M., D.T.M., J.M., O.S., H.A., A.A.-O., M.C., N.M., P.I.M., M.A.M., K.J.M.G., M.P.O., C.I.S., I.R.S., J.M.S., T.T., K.W. and C.M.D. commented on the manuscript.
Additional information

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