Abstract
Decandrinin (1), an unprecedented C$_9$-spiro-fused 7,8-seco-ent-abietane, was obtained from the bark of an Indian mangrove, Ceriops decandra, collected in the estuary of Godavari, Andhra Pradesh. The constitution and the relative configuration of 1 were determined by HRMS (ESI) and extensive NMR investigations, and the absolute configuration by circular dichroism (CD) and optical-rotatory dispersion (ORD) spectroscopy in combination with quantum-chemical calculations. Decandrinin is the first 7,8-seco-ent-abietane.

Introduction
Ceriops decandra is a mangrove of the family Rhizophoraceae. It is widely distributed along the sea coasts of South Asia down to the southern pacific islands, and of Africa and Madagascar. The genus Ceriops only consists of five mangrove plant species. Besides C. decandra, these are C. australis, C. pseudodecandra, C. tagal, and C. zippeliana [1-4]. In Indian traditional medicine,
the bark of *C. decandra* have been used for the treatment of amoebiasis, diarrhea, hemorrhage, and malignant ulcers [5], making it rewarding to screen the bioactive compounds of this plant. Before our work, already 28 compounds had been isolated from *C. decandra* [6] (three pimaranes, four beyeranes, five kauranes, and 16 lupanes). Recently, some of us have reported on the isolation of eleven new diterpenes from this plant, named decandrins A–K [7], of which nine belong to the group of abietanes.

Seco-abietane diterpenoids are a small group of natural products. To date, a total of 58 such compounds have been reported from plants of the genera *Abies*, *Cephalotaxus*, *Colus*, *Cordia*, *Hyptis*, *Isodon*, *Pinus*, *Premna*, *Salvia*, *Taiwania*, *Thuja*, and *Vitex*, including a 1,2-seco-abietane [8], a 1,10-seco-abietane [9,10], three 2,3-seco-abietanes [8,11-13], three 3,4-seco-abietanes [8,14], 31 4,5-seco-abietanes [8,15,16], ten 6,7-seco-abietanes [8,17-19], two 7,8-seco-abietanes [8,20], two 8,14-seco-abietanes [21,22], three 9,10-seco-abietanes [22,23], and two 9,11-seco-abietanes [24,25]. Among the above seco-abietanes, only laxiflorin V is a seco-ent-abietane [14]. Herein, we report on the isolation and structural elucidation of an unprecedented C9-spiro-fused 7,8-seco-ent-abietane, named decandrinin (1) (Figure 1), from the bark of an Indian mangrove, *C. decandra*, collected in the estuary of Godavari, Andhra Pradesh. The absolute stereostructure of 1 was established by HRMS (ESI), extensive NMR investigations, and by circular dichroism (CD) and optical-rotatory dispersion (ORD) spectroscopy in combination with quantum-chemical calculations.

![Figure 1: Structure of decandrinin (1).](image)

**Results and Discussion**

Decandrinin (1) was obtained as a colorless solid. Its molecular formula was established as C_{20}H_{32}O_{4} by HRMS (ESI) (m/z 333.2053, calc for [M + H]^+ 333.2060). From this formula, it was suggested that 1 has seven degrees of unsaturation, of which four could be ascribed to one carbon–carbon double bond, one lactone carbonyl group, and two keto groups, according to its $^1$H and $^{13}$C NMR data (Table 1); the molecule should thus be tricyclic.

| Position | $\delta_H$ (J in Hz) | $\delta_C$ |
|----------|----------------------|------------|
| 1α       | 1.87, m              | 31.5, CH$_2$ |
| 1β       | 2.03, m              |            |
| 2α       | 2.33, m              | 33.8, CH$_2$ |
| 2β       | 2.68, m              |            |
| 3        |                      | 213.1, C   |
| 4        |                      | 47.1, C    |
| 5        | 2.47, m              | 43.1, CH   |
| 6α       | 2.66, m              | 28.8, CH$_2$ |
| 6β       | 2.47, m              |            |
| 7        | 1.13 (3H, s)         | 30.1, CH$_2$ |
| 8        | 6.03, br s           | 124.1, CH  |
| 9        | 2.45, m              | 35.4, CH   |
| 10       | 1.11, d (6.9)        | 20.6, CH$_3$ |
| 11α      | 2.23, m              |            |
| 11β      |                      | 26.6, CH$_2$ |
| 12       | 2.52, m              |            |
| 13       |                      | 172.0, C   |
| 14       | 1.06, s              | 25.4, CH$_3$ |
| 15       | 1.13, s              | 21.6, CH$_3$ |
| 16       |                      | 14.9, CH$_3$ |
| 17       |                      |            |
| 18       |                      |            |
| 19       |                      |            |
| 20       | 1.37, s              |            |

The NMR data and a DEPT experiment (Table 1) indicated the presence of an olefinic methine group [$\delta_H$ 6.03 (br s), $\delta_C$ 124.1], two aliphatic methine groups [$\delta_H$ 2.47 (m), $\delta_C$ 43.1; $\delta_H$ 2.45 (m), $\delta_C$ 35.4], five methylene groups [$\delta_H$ 2.33 (m), 2.68 (m), $\delta_C$ 33.8; $\delta_H$ 1.87 (m), 2.03 (m), $\delta_C$ 31.5; $\delta_H$ 2.59 (m), 2.23 (m), $\delta_C$ 30.1; $\delta_H$ 2.66 (m), 2.47 (m), $\delta_C$ 28.8; $\delta_H$ 2.52 (2H, m), $\delta_C$ 26.6], five methyl groups [$\delta_H$ 1.06 (3H, s), $\delta_C$ 25.4; $\delta_H$ 1.13 (3H, s), $\delta_C$ 21.6; $\delta_H$ 1.11 (d, $J$ = 6.9 Hz, 3H), $\delta_C$ 20.8; $\delta_H$ 1.11 (d, $J$ = 6.9 Hz, 3H), $\delta_C$ 20.6; $\delta_H$ 1.37 (3H, s), $\delta_C$ 14.9], two keto groups ($\delta_C$ 213.1, 195.9), and a lactone carbonyl group ($\delta_C$ 170.9). The NMR spectroscopic data indicated that 1 was a rearranged abietane.

The existence of an isopropyl group was suggested by $^1$H,$^1$H-COSY correlations between H-15 and protons of two methyl groups [$\delta_H$ 1.11 (d, $J$ = 6.9 Hz, 3H), 1.11 (d, $J$ = 6.9 Hz, 3H)]. From $^1$H,$^1$H-COSY correlations, three further proton–proton spin systems, viz. H-21–H-22, H-22–H-2-12, and H-5–H-6, were deduced (Figure 2).

HMBC correlations between H$_{14}$/C-13, H$_{17}$/C-13, and H-14/C-15 placed the above isopropyl group at C-13, while

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**Table 1:** $^1$H (400 MHz) and $^{13}$C (100 MHz) NMR spectroscopic data for 1 in CDCl$_3$ (δ ppm).

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those from H-14 to C-9 and C-12 indicated the presence of a \(\Delta^{13,14}\) double bond. HMBC correlations from H-18, H-19, and H-2 to the carbon at \(\delta_C\) 213.1 suggested the location of a keto group at C-3, whereas those from H-11 to the carbon at \(\delta_C\) 195.9 indicated that there was another keto group at C-8 (Figure 2).

HMBC correlations from H-5 and H-6 to the carbonyl carbon (\(\delta_C\) 170.9) of a \(\delta\)-lactone suggested its location at C-7, while those from H-11, H-14, and H-20 to the quaternary carbon (\(\delta_C\) 88.3) placed it at C-9 (Figure 2).

The NOE interactions for the two methyl groups at C-4 suggested that one methyl group is located at the same side as H-5, while the other one has the same orientation as Me-20. The NOEs between the two protons of the methane at C-11 and Me-20 led to the conclusion that the carbonyl at C-8 is opposite to Me-20 (Figure 3). If the carbonyl at C-8 was oriented in the same direction as Me-20 these NOEs would not be observed because there would be several atoms between the concerned protons (Figure S9 in Supporting Information File 1). Therefore, the relative configuration of 1 was identified as shown in Figure 1.

The absolute configuration of 1 was assigned by CD and ORD spectroscopy in combination with quantum-chemical calculations. The conformational analysis of 1 by using RI-SCS-MP2/def2-TZVP//B97D/TZVP yielded six relevant conformers within the energetical range of 3 kcal/mol above the global minimum. For each of the six conformers thus identified, TDB2PLYP/def2-TZVP calculations were performed providing single UV and CD spectra, which were then summed up with Boltzmann weighting. The resulting averaged CD spectrum was corrected by a UV shift [26] of 13 nm and compared with the experimental CD curve (Figure 4). While the CD curve predicted for the 5R,9R,10S-enantiomer was nearly opposite to the one experimentally observed, the spectrum calculated for the 5S,9S,10R-enantiomer showed a good fitting with a moderate \(\Delta_{ESI}\) value of 58% [27]. To further corroborate the assignment of the absolute configuration of 1, ORD calculations were performed using the PBE0/cc-pVDZ//B97D/TZVP method. The ORD calculated for the 5S,9S,10R-configuration in the non-resonant region matched with the one observed experimentally (Figure S10 in Supporting Information File 1). The good agreement of the experimental CD and ORD spectra with the ones calculated for the 5S,9S,10R-enantiomer revealed the absolute configuration of 1 to be as shown in Figure 4.

A plausible biogenetic precursor of decandrinin (1) might be the naturally more common \(\beta\)-diastereomer of 7,13-\(\alpha\)-abietadien-3-ol (2). Accordingly, its 3\(\beta\)-OH group would be oxidized to yield int A, whose C-9 would then be hydroxylated to afford int B. Oxidative cleavage at the \(\Delta^{7,8}\) double bond of int B could yield int C. Finally, the lactonization of int C would give decandrinin (1) (Scheme 1).

Experimental

General methods

Optical rotation values were recorded on a JASCO P-1020 polarimeter. CD spectra were recorded on a J-715 spectropolarimeter (JASCO, Gross-Umstadt, Germany). UV spectra were obtained on a Beckman DU-640 UV spectrophotometer. NMR spectra were performed on a Bruker maXis UHR-TOF mass spectrometer in positive ion mode. For column chromatography, silica gel (200–300 mesh, Qingdao Mar. Chem. Ind. Co. Ltd.) and RP C\(18\) gel (YMC) were used. High-performance liquid chromatography (HPLC) was performed on a Shimadzu LC-6AD controller with an SPD-20A UV–vis detector equipped with YMC-Pack ODS-A columns (250 \(\times\) 10 mm i.d., 5 \(\mu\)m and 250 \(\times\) 4.6 mm i.d., 5 \(\mu\)m).
Plant material
As described previously [7] the bark of Ceriops decandra were collected in September 2009 in the estuary of Godavari, Andhra Pradesh, India. The identification of the plant was performed by one of the authors (T.S.). A voucher sample (No. CD-001) is maintained at the Marine Drugs Research Center, College of Pharmacy, Jinan University.

Extraction and isolation
The extraction and isolation procedures were in part identical to those described recently [7]: The chloroform extract (65.2 g) from air-dried bark (7.4 kg) of C. decandra was subjected to silica-gel column chromatography (200–300 mesh, 3.0 kg) and eluted with petroleum ether/acetone (100:0 to 1:2) to yield 285 fractions. Fractions 173 to 204 were combined and further
purified using RP C\textsubscript{18} column chromatography eluted with acetone/H\textsubscript{2}O (30:70 to 100:0) to give 57 subfractions. Subfractions 8–13 were combined and subjected to preparative HPLC (YMC-Pack 250 × 10 mm i.d., MeCN/H\textsubscript{2}O, 32:68) to afford eight subfractions. Then the sixth subfraction was further purified by HPLC (YMC-Pack 250 × 4.6 mm i.d., MeOH/H\textsubscript{2}O, 40:60) to provide I (1.9 mg).

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**Supporting Information**

Supporting Information File 1

HRMS (ESI) and NMR spectra of decandrinin (1), NOE interactions for the B97D/TZVP-optimized structure diagnostic for the 9-epimer of decandrinin (I), and comparison of the calculated ORD with the experimental one.

[http://www.beilstein-journals.org/bjoc/content/supplementary/1860-5397-10-23-S1.pdf]
