JOC The Journal of Organic Chemistry

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Cobalt-Catalyzed [6 + 2] Cycloaddition of Alkynes with 1,3,5,7-Cyclooctatetraene as a Key Element in the Direct Construction of Substituted Bicyclo[4.3.1]decanes

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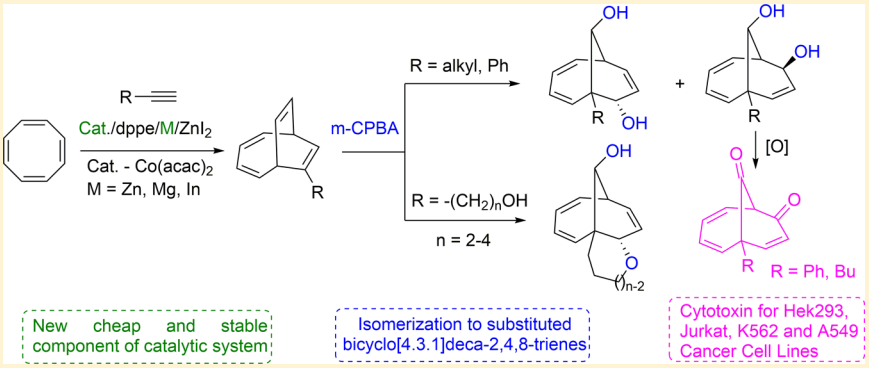
Supporting Information



ABSTRACT: A new, effective catalytic system based on $Co(acac)_2$ has been developed for [6 + 2] cycloaddition of terminal alkynes to 1,3,5,7-cyclooctatetraene to give substituted bicyclo[4.2.2]deca-2,4,7,9-tetraenes in high yields (68−85%). The electrophilic activation of double bonds in the bicyclic products with m-CPBA is an efficient method for the synthesis of substituted bicyclo[4.3.1]deca-2,4,8-triene-7,10-diols, which form the key structural moieties of numerous natural biologically active compounds. The structures of the obtained compounds were reliably proven by modern spectral methods and X-ray diffraction. The mechanism of the discovered rearrangement was studied both using deuterium-labeled bicyclo[4.2.2]deca-2,4,7,9-tetraenes and utilizing quantum chemical calculations. The obtained substituted bicyclo[4.3.1]deca-2,4,8-triene-7,10-diols and their keto derivatives showed high antitumor activity in vitro against Hek293, Jurkat, K562, and A549 tumor cell lines.

INTRODUCTION

The bicyclo[4.3.1]decane core is the key structural unit of many natural biologically active compounds, such as caryolane, phomoidride B, vibsanines, welwitindolinones, nakafuran-9, pallescensins C and D, florlides, and so on (Figure 1),[1] which exhibit anti-HIV, antitumor, antimicrobial, antibacterial, and antimycotic properties.[1f,2] These compounds contain diverse functional groups and numerous asymmetric centers; the choice of a strategy for forming the bicyclo[4.3.1]decane core, which would determine the sequence of transformations to prepare the desired compound, is a key problem in planning their total syntheses. With a more extensive range of preparation methods for these bicyclic products being at the disposal of a synthetic chemist, the final goal will be achieved more efficiently. The most popular methods for the formation of bicyclo[4.3.1]decanes are based on metathesis, intramolecular Diels−Alder reactions, Pd-catalyzed [6 + 3] cycloaddition of trimethylenemethane to tropones, and Cu-catalyzed [3 + 3] cycloaddition of propargyl esters to cyclic enamines.[1a,3]

We found a single example of the synthesis of bicyclo[4.3.1]-deca-2,4,8-trienes (Scheme 1)[4] and no examples of their rearrangement to bicyclo[4.2.2]deca-2,4,7,9-tetraenes involving substituted substrates.

No data on the possibility of extending this rearrangement to substituted bicyclo[4.2.2]deca-2,4,7,9-tetraenes were reported in the literature before our study.

This reaction has significant synthetic potential, because the preparation of bicyclo[4.3.1]decanes with various substituents is accompanied by simultaneous introduction of reactive functional groups into the molecules, which allows for further targeted transformations into useful compounds with specific properties.

Received: October 19, 2016
Published: December 9, 2016

DOI: 10.1021/acs.joc.6b02540
J. Org. Chem. 2017, 82, 471−480

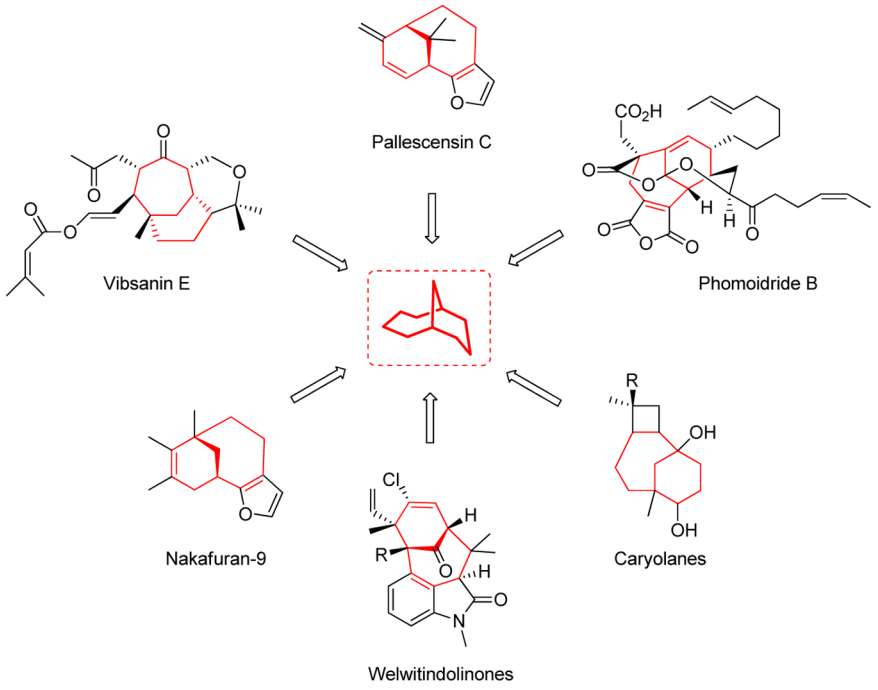
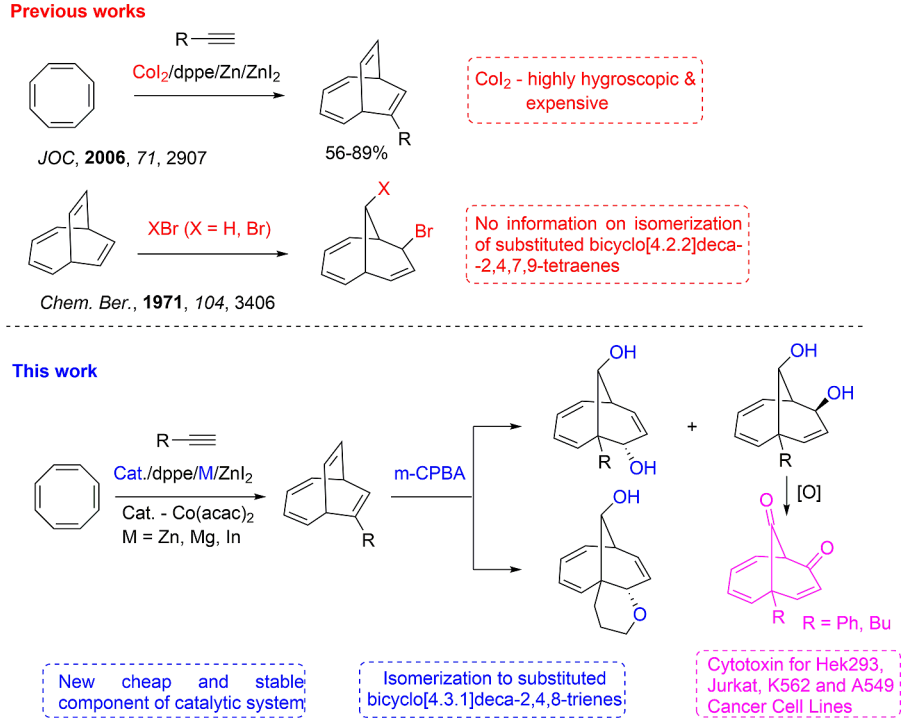


Figure 1. Some natural biologically active compounds containing the bicyclo[4.3.1]decane core.

Scheme 1. Schematic View of the Goals of Our Investigation in Comparison with Known Published Data



Substituted bicyclo[4.2.2]deca-2,4,7,9-tetraenes are accessible compounds owing to the recently developed Co-catalyzed [6 + 2] cycloaddition reactions of alkynes with 1,3,5,7-cyclooctatetraene (COT) (Scheme 1).[5]

The key goals of this investigation (Scheme 1) are the development of an efficient and selective catalyst for [6 + 2]-cycloaddition of alkynes to 1,3,5,7-cyclooctatetraene, the use of substituted bicyclo[4.2.2]deca-2,4,7,9-tetraenes in the synthesis of bicyclo[4.3.1]decanes, and an evaluation of the antitumor activity *in vitro* of these products.

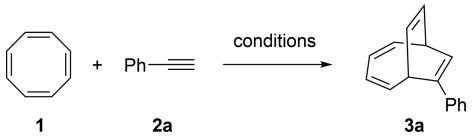
RESULTS AND DISCUSSION

Development of a Catalytic System for [6 + 2] Cycloaddition Reactions of Alkynes with COT. The development of an efficient method for the synthesis of bicyclo[4.3.1]decanes required a convenient method for the synthesis of potential precursors: namely, bicyclo[4.2.2]deca-2,4,7,9-tetraenes (Scheme 1). Among the currently known methods for the synthesis of bicyclo[4.2.2]deca-2,4,7,9-tetraenes, the method of Buono et al.,[5] based on [6 + 2]

DOI: 10.1021/acs.joc.6b02540
J. Org. Chem. 2017, 82, 471−480

cycloaddition of alkynes to COT catalyzed by three- or four-component CoI_2(dppe)/Zn/ZnI_2 (CoI_2/dppe/Zn/ZnI_2) systems (Scheme 1), seemed most appropriate for the preparation of key bicyclic compounds in gram amounts. A considerable drawback of this method is the necessity of using expensive diiodo(bis(diphenylphosphino)ethane)cobalt(II) or highly hygroscopic cobalt(II) iodide. We attempted to develop a new catalytic system with replacement of CoI_2 by more readily accessible and stable Co compounds, for example, $Co(acac)_2$, $Co(acac)_3$, $CoCl_2$, $CoBr_2$, and $Co(OAc)_2$, and with the use of new activating ligands and reducing agents (Table 1).

Table 1. Optimization of Reaction Conditions for the [6 + 2] Cycloaddition of COTT (1) to Phenylacetylene (2a)[a]



1 2a 3a

entry	catalyst	ligand	Lewis acid	reducing agent	yield[b] (%)
1	$Co(acac)_2$	dppe	ZnI_2	Zn	75
2	$Co(acac)_2$	dppe		Et_2AlCl	
3	$Co(acac)_2$	dppe	$InCl_3$	In	
4	CoI_2	dppe	ZnI_2	In	71
5	CoI_2	dppe		In	
6	$Co(acac)_2$	PPh_3	ZnI_2	Zn	
7	$Co(acac)_2$	$P(OPr^i)_3$	ZnI_2	Zn	
8	$Co(OAc)_2$	dppe	ZnI_2	Zn	70
9	$CoBr_2$	$P(OPr^i)_3$	ZnI_2	Zn	
10	$CoCl_2$	dppe	ZnI_2	Zn	70
11	$Co(acac)_3$	dppe	ZnI_2	Zn	72
12	$Co(acac)_2$	dppm	ZnI_2	Zn	25
13	$Co(acac)_2$	dppp	ZnI_2	Zn	
14	$Co(acac)_2$	dppb	ZnI_2	Zn	
15	$Co(acac)_2$	dppe	ZnI_2	Mg	69
16	$Co(acac)_2$	$P(Cy)_3$	ZnI_2	Zn	
17	$Co(acac)_2$	XPhos	ZnI_2	Zn	
18	$Co(acac)_2$	CyJohnPhos	ZnI_2	Zn	
19	$Co(acac)_2$	*t*-BuXPhos	ZnI_2	Zn	
20	$Co(acac)_2$	SPhos	ZnI_2	Zn	
21	$Co(acac)_2$	JohnPhos	ZnI_2	Zn	
22	$Co(acac)_2$	DowePhos	ZnI_2	Zn	
23	$Co(acac)_2$	P(*o*-Tol)$_3$	ZnI_2	Zn	

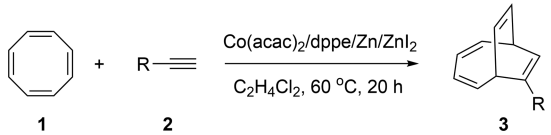
[a]Reaction conditions: COT **1**/C_8H_6 **2a**/catalyst/ligand/reducing agent/Lewis acid = 1.2/1/0.1/0.1/0.3/0.2, $C_2H_4Cl_2$, 60 °C, 20 h. [b]Yields of isolated products by column chromatography.

We found that CoI_2 can be successfully replaced by $Co(acac)_2$, $Co(acac)_3$, or $Co(OAc)_2$. With $Co(acac)_2$ as the catalyst, the yield of 7-phenylbicyclo[4.2.2]deca-2,4,7,9-tetraene (**3a**) was ~75%. The use of $Co(acac)_2$ is preferred, because its cost is 2 orders of magnitude lower than the cost of cobalt(II) iodide.[6]

Furthermore, after being stored in air for 1 week, $Co(acac)_2$ did not lose activity unlike CoI_2, was deliquescent, and became unusable within several hours under similar conditions. The replacement of Zn by Mg or In has virtually no influence on the yield of the target bicyclic product **3a** (Table 1). It was found that dichloroethane can be replaced by an aromatic (benzene, toluene) or aliphatic solvent (hexane, heptane, octane).

The cycloaddition of various substituted alkynes **2** to COT (**1**) was conducted in the presence of the modified $Co(acac)_2$/dppe/Zn/ZnI_2 catalytic system to give the target bicyclo[4.2.2]-deca-2,4,7,9-tetraenes **3** in 68−85% yields (Table 2).

Table 2. Cobalt-Catalyzed [6 + 2] Cycloaddition of COT (1) with Alkynes (2)[a]



1 2 3

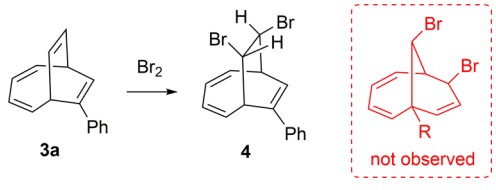
entry	alkyne	R	product	yield[b] (%)
1	**2a**	Ph	**3a**	75
2	**2b**	Bu	**3b**	70
3	**2c**	Hex	**3c**	68
4	**2d**	Oct	**3d**	72
5	**2e**	$-(CH_2)_4CCSiMe_3$	**3e**	82
6	**2f**	$-(CH_2)_2OAc$	**3f**	80
7	**2g**	-$SiMe_3$	**3g**	83
8[c]	**2h**	$-(CH_2)_2OH$	**3h**	78
9	**2i**	$-(CH_2)_3OH$	**3i**	85
10	**2j**	$-(CH_2)_4OH$	**3j**	82

[a]Reaction conditions unless specified otherwise: COT **1**/alkyne **2**/$Co(acac)_2$/dppe/Zn/ZnI_2 = 1.2/1/0.1/0.1/0.3/0.2, $C_2H_4Cl_2$, 60 °C, 20 h. [b]Yields of isolated products by column chromatography. [c]TFE as solvent, catalyst $Co(acac)_2$(dppe)

Isomerization of Bicyclo[4.2.2]deca-2,4,7,9-tetraenes 3 into Bicyclo[4.3.1]deca-2,4,8-triene-7,10-diols 5 and 6 Induced by m-CPBA. In the next stage of our research, we attempted to perform skeletal isomerization of the prepared bicyclo[4.2.2]deca-2,4,7,9-tetraenes via electrophilic double-bond activation by treatment with molecular Br_2 to give the target 7,10-dibromobicyclo[4.3.1]deca-2,4,8-trienes.

The reaction of 7-phenylbicyclo[4.2.2]deca-2,4,7,9-tetraene (**3a**) with Br_2 under the chosen conditions (**3a**/Br_2 = 1/1, $CHCl_3$, −75 °C) served as the model reaction (Scheme 2).

Scheme 2. Reaction of 7-Phenylbicyclo[4.2.2]deca-2,4,7,9-tetraene (3a) with Br_2



3a 4

Instead of the expected 7,10-dibromobicyclo[4.3.1]deca-2,4,8-trienes, the reaction selectively affords 9,10-dibromo-7-phenylbicyclo[4.2.2]deca-2,4,7-triene (**4**; 70% yield), resulting from the addition of bromine to the C(9)−C(10) double bond of adduct **3a**.

Having failed to perform skeletal isomerization of substituted bicyclo[4.2.2]deca-2,4,7,9-tetraenes by means of Br_2, which is a weak electrophile, we thought that *m*-chloroperbenzoic acid, a conventional electrophilic reagent, would be suitable for this goal. When bicyclo[4.2.2]deca-2,4,7,9-tetraenes **3a−e** were made to react with m-CPBA in a 1:1.4 ratio under the chosen conditions (CH_2Cl_2, 0 °C (3 h), 25 °C (12 h)), the target bicyclo[4.3.1]deca-2,4,8-triene-7,10-diols **5** and **6**, rather than

DOI: 10.1021/acs.joc.6b02540
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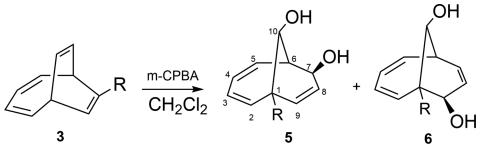
the expected oxiranes, were formed in more than 80% yields as mixtures of two regioisomers (Table 3). Each isomer was isolated in a pure state by column chromatography, and their structures were proved by 1D and 2D NMR techniques.

Table 3. Reaction of Bicyclo[4.2.2]deca-2,4,7,9-tetraenes 3a–e with m-CPBA[a]



entry	bicyclo[4.2.2]deca-2,4,7,9-tetraene	R	5a–e:6a–e[b]	yield[c] (%)
1	**3a**	Ph	1:0	82
2	**3b**	Bu	1:1	80
3	**3c**	Hex	1:1	81
4	**3d**	Oct	1:1	79
5	**3e**	$-(CH_2)_4CCSiMe_3$	1:1	78

[a]Reaction conditions: bicyclo[4.2.2]deca-2,4,7,9-tetraene **3**/m-CPBA = 1/1.4, CH_2Cl_2, 0 °C (3 h), 25 °C (12 h). [b]Ratio determined by ^{1}H NMR. [c]Yields of isolated products by column chromatography.

1-Phenylbicyclo[4.3.1]deca-2,4,8-triene-7,10-diol (**5a**) thus obtained was a crystalline solid, and crystals were obtained that were suitable for X-ray diffraction. The X-ray diffraction data for **5a** unambiguously demonstrate that the hydroxyl group at the C(10) bridging carbon atom has an anti orientation relative to the butadiene skeleton of the molecule and that the hydroxyl at C(7) has an exo orientation relative to the bridging part of the molecule (Figure 2).

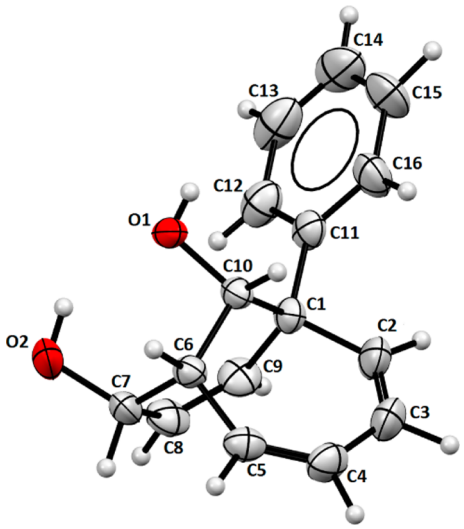
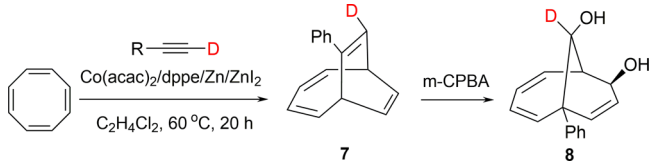


Figure 2. Structure of compound **5a** in the crystal (ellipsoid contour probability 50%).

In order to elucidate the stereochemical orientation of hydroxyl groups of other substituted examples of **5** (**5b–e**), 2D NMR experiments were conducted. The NOESY spectrum of 1-butylbicyclo[4.3.1]deca-2,4,8-triene-7,10-diol (**5b**) exhibited intense cross peaks between the proton signals of two hydroxyl groups and one β-methylene proton of the butyl group, as a result of polarization transfer in the three-proton system, which is indicative of spatial proximity of the protons at C(10)–OH, C(7)–OH, and C(11)–H_β. This configuration implies an anti orientation of the hydroxyl group at the C(10) bridging atom and exo orientation at the C(7) atom. Similarly, according to the NOESY experiments, the second regioisomer, 6-butylbicyclo[4.3.1]deca-2,4,8-triene-7,10-diol (**6b**), had anti- and exo-oriented hydroxyl groups.

In order to elucidate the mechanism of the skeletal isomerization of bicyclo[4.2.2]deca-2,4,7,9-tetraenes into bicyclo[4.3.1]deca-2,4,8-trienes, we studied the reaction of monodeuterated 7-phenylbicyclo[4.2.2]deca-2,4,7,9-tetraene (**7**) as a model compound with *m*-chloroperbenzoic acid under the developed optimal conditions (CH_2Cl_2, 0 °C (3 h), 25 °C (12 h)). Under the chosen conditions, the reaction gave monodeuterated 1-phenylbicyclo[4.3.1]deca-2,4,8-triene-7,10-diol (**8**) in 80% yield (Scheme 3). The carbon NMR spectrum

Scheme 3. Reaction of 7-Phenyl-8-deuterobicyclo[4.2.2]deca-2,4,7,9-tetraene (7) with m-CPBA



of **8** indicates that the deuterium atom is found on the bridging C(10) carbon. Thus, it can be determined quite strictly which part of the carbon skeleton of the starting molecule **7** forms the bridging group in molecule **8**.

According to published data, the rate of alkene epoxidation with m-CPBA increases with increasing electron density at the double bond.[7] The alkyl or aryl substituent in position 7 of bicyclo[4.2.2]deca-2,4,7,9-tetraene **A** increases the nucleophilicity of the substituted double bond and is favorable for selective epoxidation (Scheme 4). According to our experimental data, the reaction is stereoselective, giving exclusively the exo-addition product **B**. The subsequent protonation of the oxygen atom by *m*-chlorobenzoic acid makes the oxirane more electrophilic. By calculation of the Fukui indices in the B3LYP/6-31G(d,p) basis set, we identified the preferred sites of nucleophilic and electrophilic attacks in molecule **C** (Table 4). According to this analysis, an intramolecular electrophilic attack may occur at C(2) and C(5) atoms. Calculation data also attest to the preferred intramolecular nucleophilic attack at C(7), C(2), and C(5) atoms. Thus, upon cleavage of the protonated oxirane ring, one can expect an intramolecular rearrangement to yield intermediate **D** (via nucleophilic attack of C(5) at C(7)) or **E** (via nucleophilic attack of C(2) at C(7)). According to these calculations, the formation of intermediate **D** is more favorable. The difference between the free energies of formation of intermediates **D** and **E** is 14.2 kcal/mol. It is worth noting that we failed to locate, on the potential energy surface, carbocation **F**, which could have resulted from cleavage of the protonated oxirane ring. The conversion of intermediate **C** to **D** occurs virtually without a barrier via the butterfly-like transition state **G**, the activation energy of the conversion being 0.1 kcal/mol. Intermediate **D** is a substituted bis-homotropylium cation, which is homoaromatic.[8] Its formation was postulated previously for rearrangements of bicyclo[4.3.1]-decatriene and its derivatives.[4,9] According to the calculated Fukui indices, the preferred sites for nucleophilic attack in carbocation **D** are positions at C(7), C(9), C(3), and C(5).

DOI: 10.1021/acs.joc.6b02540
J. Org. Chem. 2017, 82, 471–480

Scheme 4. Putative Mechanism for the Transformation of Substituted Bicyclo[4.2.2]deca-2,4,7,9-tetraenes into Substituted Bicyclo[4.3.1]deca-2,4,8-triene-7,10-diols under the Action of m-CPBA

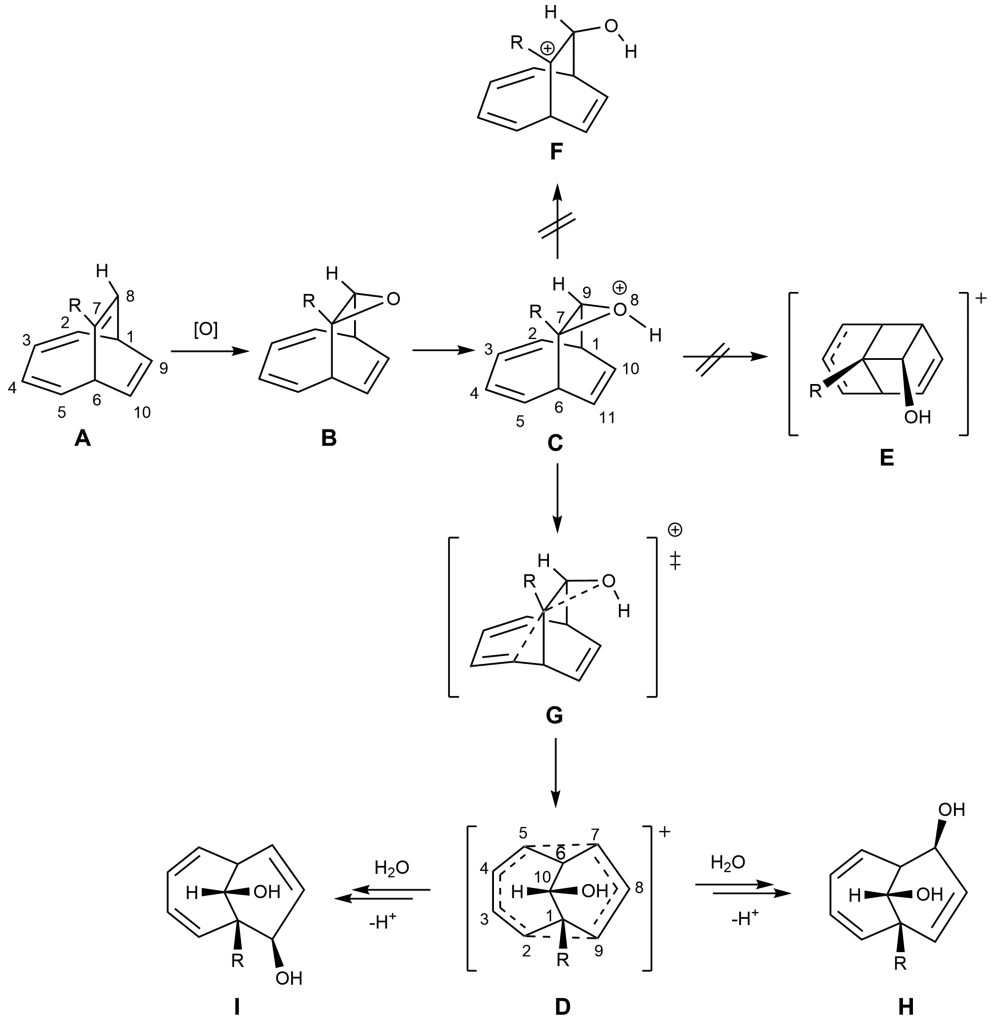


Table 4. Fukui Indices for Intermediates C and D (R = Me) Calculated by the B3LYP/6-31G(d,p) Method

	intermediate **C**		
atom no.	f^+	f^-	intermediate **D** f^+
1	−0.022	−0.029	−0.001
2	0.151	0.240	0.003
3	0.055	0.070	0.134
4	0.077	0.069	0.023
5	0.140	0.244	0.092
6	−0.023	−0.029	−0.007
7	0.082	−0.009	0.135
8			−0.004
9	0.023	−0.009	0.178
10	0.012	0.016	0.017
11	0.005	0.010	

Addition of a nucleophile to positions at C(3) and C(5) is thermodynamically unfavorable, as this gives strained structures containing a cyclopropane moiety. An attack of a water molecule on positions at C(7) and C(9) yields dihydroxy derivatives **H** and **I**, respectively. Despite the higher $f(+)$ value of C(9) in intermediate **D**, a substituent at C(1) reduces the spatial accessibility of the electrophilic carbon atom. In the case of a bulky phenyl substituent, the reaction involves only C(7) and gives compound **H**. However, the alkyl-substituted bis-homotropylium cation gives a mixture of C(7)-addition (**H**) and C(9)-addition (**I**) products in an ∼1:1 ratio, indicating that the energy barriers for the formation of these products are comparable.

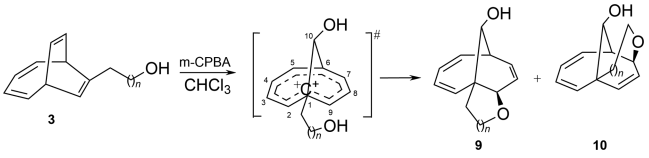
Fairly interesting results were obtained upon the oxidation of COT adducts with alkynol. The reaction of **3h−j** with *m*-chloroperbenzoic acid is accompanied by intramolecular cyclization to give tricyclic alcohols **9** and **10** (Table 5).

The tricyclic compound **9i** was a crystalline solid, and its structure was established by X-ray diffraction. The X-ray diffraction data unambiguously prove the anti orientation of the hydroxyl group at the bridging carbon atom relative to the butadiene skeleton and the exo orientation of the tetrahydropyran moiety relative to the bridging part of the molecule (Figure 3).

This reaction is a result of the fact that the cation (Table 5) contains a hydroxyl group that can act as a nucleophile. As noted above, the reaction gives rise to a bis-homotropylium cation. Thus, the hydroxyl attacks the electrophilic site of the bis-homotropylium cation; this furnishes a five-, six-, or seven-membered ring. It is noteworthy that, in the case of codimers **3h,i**, the hydroxyl group attacks only at C(9). Conversely, adduct **3j** containing a butanol substituent reacts not only at C(9) but also at C(7) to give tricyclic compounds **9j** and **10j** in

DOI: 10.1021/acs.joc.6b02540
J. Org. Chem. 2017, 82, 471−480

Table 5. Reaction of 7-(ω-Hydroxyalkyl)bicyclo[4.2.2]deca-2,4,7,9-tetraenes 3h−j with m-CPBA[a]



entry	bicyclo[4.2.2]deca-2,4,7,9-tetraene	*n*	9h−j:10h−j[b]	yield[c] (%)
1	**3h**	1	1:0	72
2	**3i**	2	1:0	69
3	**3j**	3	5:1[b]	65

[a]Reaction conditions: bicyclo[4.2.2]deca-2,4,7,9-tetraene **3**/m-CPBA = 1/1.4, $CHCl_3$, 0 °C (3 h), 40 °C (3 h), 25 °C (12 h). [b]Ratio determined by ^1H NMR. [c]Yields of isolated products by column chromatography.

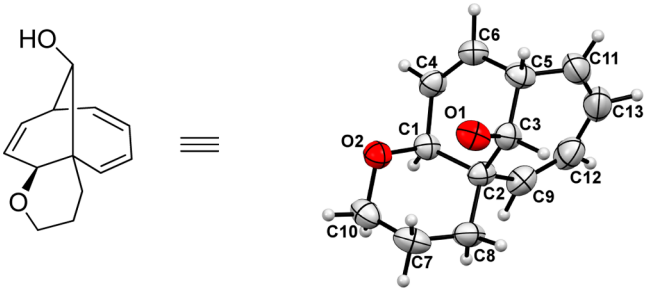


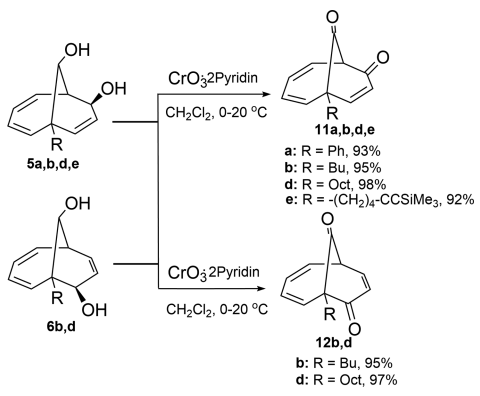
Figure 3. Structure of compound **9i** in the crystal (ellipsoid contour probability 50%).

a 5:1 ratio. Apparently, in this case, the arrangement of the hydroxyl group relative to the C(7) electrophilic center is more favorable for nucleophilic attack than in the case of ethanol or propanol substituents.

It is necessary to mention that the hydroxyl groups present in the bicyclo[4.3.1]deca-2,4,8-triene-7,10-diol molecule are by themselves reaction sites bearing a huge potential for further transformations. For example, oxidation of the hydroxyl groups of bicyclo[4.3.1]deca-2,4,8-triene-7,10-diols **5a,b,d,e** and **6b,d** on treatment with Sarett reagent, a chromium oxide complex with pyridine, furnished bicyclo[4.3.1]deca-2,4,8-triene-7,10-diones **11a,b,d,e** and **12b,d** in virtually quantitative yields (Scheme 5).

In Vitro Antitumor Activities of Bicyclo[4.3.1]deca-2,4,8-triene-7,10-diols 5a,b and Their Keto Derivatives

Scheme 5. Sarett Oxidation of Bicyclo[4.3.1]deca-2,4,8-triene-7,10-diols 5a−e and 6b,d



11a,b. It is known from the literature that some structural derivatives of natural compounds are often much more active than the parent compounds. Therefore, investigation of the modified analogues of highly active natural products seems fairly promising. Considering the structural similarity of the prepared bicyclo[4.3.1]decanes with some natural compounds,[1] which exhibit a wide range of biological activities, it seemed of practical interest to assess the antitumor activity in vitro of some of the compounds that were synthesized.

The experimental results indicate that the Hek293, Jurkat, K562, and A549cell lines showed different degrees of sensitivity to the tested series of with bicycles **5a,b** and **11a,b**. The clear-cut heterogeneity of the IC_{50} values demonstrated for different tumor cell lines in vitro is a key factor indicative of a specific antitumor activity rather than nonspecific toxicity, in which case the inhibitory concentration (IC_{50}) values obtained for different cell lines would be similar.[10]

The IC_{50} values for the tested compounds were in the range between 0.24 ± 0.02 and 2.1 ± 0.2 μM. Compound **11a** was the most active inhibitor of the HEK293, Jurkat, A549, and K562 tumor cell growth, as it inhibited cell viability when present in lower concentrations (IC_{50} of 0.24 ± 0.02 to 0.58 ± 0.05 μM) in comparison to camptothecin (IC_{50} of 25.17 ± 0.9 to 82.9 ± 1.3 μM) or etoposide (IC_{50} of 19.45 ± 0.8−74.5 ± 1.8 μM). It was also demonstrated that its diol analogue **5a** has a weaker cytotoxic activity toward HEK293, Jurkat, and K562 (IC_{50} of 0.84 ± 0.09 to 1.74 ± 0.18 μM). Weak antitumor activities in vitro were found for compounds **5b** and **11b**, the IC_{50} values being 1.12 ± 0.11−2.1 ± 0.2 μM.

CONCLUSIONS

A new, effective catalytic system based on $Co(acac)_2$ has been developed for [6 + 2] cycloadditions of terminal alkynes to 1,3,5,7-cyclooctatetraene to give substituted bicyclo[4.2.2]deca-2,4,7,9-tetraenes in high yields (68−85%). Oxidation of bicyclo[4.2.2]deca-2,4,7,9-tetraenes with *m*-chloroperbenzoic acid resulted in the formation of bicyclo[4.3.1]deca-2,4,8-triene-7,10-diols in 78−82% yields. The proposed method for the synthesis of the bicyclo[4.3.1]decane system may serve as an alternative to the existing methods for the preparation of molecules of this type and could be used as the key steps in the syntheses of important biologically active compounds. In addition, the cytotoxicity of the synthesized compounds is being actively investigated and we hope that significant results will be achieved in the future in this area.

EXPERIMENTAL SECTION

General Information. Chromatographic analysis was performed on a chromatograph using a 2000 × 2 mm column, SE-30 (5%) stationary phase on Chromaton N-AW-HMDS (0.125−0.160 mm), helium carrier gas (30 mL/min),and temperature programming from 50 to 300 °C at a 8 °C/min rate. Flash column chromatography was performed over silica gel 0.060−0.200 mm, 60 A. The ^1H and ^{13}C NMR spectra were recorded for $CDCl_3$ solutions at 100 MHz for ^{13}C and 400 MHz for ^1H and at 125 MHz for ^{13}C and 500 MHz for ^1H. The chemical shifts are reported as δ values in parts per million relative to the internal standard Me_4Si. The coupling constants (*J*) are reported in hertz. X-ray diffraction analysis was performed on an four-circle automated diffractometer (graphite monochromator, Mo Kα radiation, λ = 0.71073 Å, ω-scan mode, $2\theta_{max}$ = 62°). The data were collected and treated by using the Oxford Diffraction Ltd. CrysAlis^{Pro} program package, version 1.171.36.20. The structures were solved by direct methods and refined by full-matrix least-squares methods in the anisotropic approximation for non-hydrogen atoms. The hydrogen

DOI: 10.1021/acs.joc.6b02540
J. Org. Chem. 2017, 82, 471−480

atoms were located on electron density maps and refined in the isotropic approximation. The refinement was done using the SHELX97 program package.[11] Samples of cells treated with synthesized compounds were analyzed on a flow cytometry system. Mass spectra were obtained with a spectrometer at 70 eV and a working temperature of 200 °C. High-resolution mass spectra (HRMS) were measured on a instrument using a time-of-flight mass analyzer (TOF) with electrospray ionization (ESI). In experiments on selective collisional activation, the activation energy was set at maximum abundance of fragment peaks. A syringe injection was used for solutions in MeCN/H_2O, 50/50 v/v (flow rate 3 mL/min). Nitrogen was applied as a dry gas; the interface temperature was set at 180 °C. IR spectra were recorded on a spectrometer as liquid films and are reported in wavenumbers (cm^{-1}). All solvents were dried and freshly distilled before use. Cycloaddition reactions were carried out under a dry argon atmosphere. COT, all of the terminal alkynes, alkynols, $Co(acac)_2$, CoI_2, 1,2-bis(diphenylphosphino)ethane, and *m*-chloroperbenzoic acid (70−75%, balance 3-chlorobenzoic acid and water) were purchased from commercial sources and used without further purification. Ethynyl(trimethyl)silane, trimethyl(1,7-octadiynyl)silane, and 3-butynyl acetate were prepared according to literature procedures.[12]

Cycloaddition of 1,3,5,7-Cyclooctatetraene and Alkynes (General Procedure). Zn powder (30 mol %) was added to a solution of $Co(acac)_2$ (10 mol %) and dppe (10 mol %) in DCE (1.5 mL) in a glass ampule under a dry argon atmosphere, and the mixture was stirred at room temperature for 2 min. Next, COT (1.2 mmol), the alkyne (1.0 mmol) in DCE (1.5 mL), and dry ZnI_2 (20 mol %) were added successively. The ampule was sealed, and after it was heated at 60 °C for 20 h, it was opened and the reaction was stopped by the addition of petroleum ether and stirring in air for 10 min to deactivate the catalyst. After filtration through a short pad of silica, the volatiles were removed under vacuum. Chromatographic purification over SiO_2 (100% petroleum ether as the eluent) afforded the target products **3a−j** and **7**. All analytical data recorded for compounds **3a**,**b**,**f−h** were in full accord with previously published data.[5]

*7-Phenylbicyclo[4.2.2]deca-2,4,7,9-tetraene (**3a**).* Yield: 0.155 g (75%), colorless oil. R_f = 0.65. ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.45 (d, J = 7.7 Hz, 2H), 7.36 (t, J = 7.6 Hz, 2H), 7.27 (dd, J = 12.7 Hz, J = 5.3 Hz, 1H), 6.40−6.46 (m, 1H), 6.32−6.38 (m, 1H), 6.10 (d, J = 6.3 Hz, 1H), 5.85−5.92 (m, 3H), 5.77 (dd, J = 8.7 Hz, J = 5.9 Hz, 1H), 3.88 (dd, J = 8.5 Hz, J = 6.3 Hz, 1H), 3.41 (dt, J = 8.7 Hz, J = 6.1 Hz, 1H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 141.9, 141.0, 139.8, 135.1, 128.4 (2C), 126.7, 126.5 (2C), 124.8, 124.7, 121.6, 120.5, 119.8, 38.3, 35.5 ppm. IR (liquid film): 3020, 3011, 2904, 1597, 1484, 1443 cm^{-1}. MS (EI, 70 eV) m/z (%): 206 $[M]^+$ (66), 191 (31), 178 (13), 165 (13), 128 (66), 91 (75), 77 (28), 51 (24), 40 (100). Anal. Calcd for $C_{16}H_{14}$: C, 93.16; H, 6.84. Found: C, 93.29; H, 6.64.

*7-Butylbicyclo[4.2.2]deca-2,4,7,9-tetraene (**3b**).* Yield: 0.130 g (70%), colorless oil. R_f = 0.58. ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.26−6.31 (m, 1H), 6.20−6.25 (m, 1H), 5.77−5.81 (m, 2H), 5.72−5.76 (m, 1H), 5.68 (dd, J = 8.7 Hz, J = 5.8 Hz, 1H), 5.43 (d, J = 6.1 Hz, 1H), 3.26 (dd, J = 5.9 Hz, J = 8.7 Hz, 1H), 3.17 (dt, J = 8.6 Hz, J = 6.0 Hz, 1H), 2.12 (t, J = 7.6 Hz, 2H), 1.39−1.44 (m, 3H), 1.28−1.33 (m, 1H), 0.92 (t, J = 7.3 Hz, 3H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): 142.0, 141.8, 136.6, 124.3, 123.9, 121.4, 121.1, 116.9, 39.2, 35.1, 34.7, 31.2, 22.4, 14.0 ppm. IR (liquid film): 3015, 2960, 2923, 2865, 1487, 1390 cm^{-1}. MS (EI, 70 eV) m/z (%): 186 $[M]^+$ (<1), 141 (9), 129 (100), 115 (19), 91 (9), 77 (10), 51 (7), 41 (13). Anal. Calcd for $C_{14}H_{18}$: C, 90.26; H, 9.74. Found: C, 90.12; H, 9.91.

*7-Hexylbicyclo[4.2.2]deca-2,4,7,9-tetraene (**3c**).* Yield: 0.146 g (68%), colorless oil. R_f = 0.61. ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.18−6.31 (m, 2H), 5.62−5.79 (m, 4H), 5.43 (d, J = 6.0 Hz, 1H), 3.26 (dd, J = 8.5, 6.0 Hz, 1H), 3.17 (dd, J = 14.5, 5.9 Hz, 1H), 2.10 (t, J = 7.5 Hz, 1H), 1.41−1.44 (m, 1H), 1.23−1.37 (m, 8H), 0.91 (t, J = 6.7 Hz, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): 142.0, 141.8, 136.6, 124.3, 123.9, 121.4, 121.1, 116.9, 39.3, 35.1, 35.0, 31.8, 29.0 (2C), 22.6, 14.1 ppm. IR (liquid film): 3011, 2955, 2855, 1465, 1378 cm^{-1}. MS (EI, 70 eV) m/z (%): 214 $[M]^+$ (<1), 143 (4), 129 (100), 115 (10), 91 (5), 77 (4), 65 (3), 41 (9). Anal. Calcd for $C_{16}H_{22}$: C, 89.65; H, 10.35. Found: C, 89.50; H, 10.20.

*7-Octylbicyclo[4.2.2]deca-2,4,7,9-tetraene (**3d**).* Yield: 0.174 g (72%), colorless oil. R_f = 0.60. ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.26−6.30 (m, 1H), 6.18−6.22 (m, 1H), 5.75−5.79 (m, 2H), 5.70−5.74 (m, 1H), 5.66 (dd, J = 8.7 Hz, J = 5.8 Hz, 1H), 5.41 (d, J = 6.1 Hz, 1H), 3.25 (dd, J = 8.7 Hz, J = 5.9 Hz, 1H), 3.16 (dt, J = 8.7 Hz, J = 5.9 Hz, 1H), 2.09 (t, J = 7.6 Hz, 1H), 1.38−1.44 (m, 1H), 1.27−1.33 (m, 12H), 0.90 (t, J = 6.9 Hz, 3H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): 142.0, 141.8, 136.6, 124.3, 123.9, 121.4, 121.1, 116.9, 39.2, 35.1, 35.0, 31.9, 29.5, 29.3, 29.3, 29.0, 22.7, 14.1 ppm. IR (liquid film): 3014, 2952, 2857, 1461, 1380 cm^{-1}. MS (EI, 70 eV) m/z (%): 242 $[M]^+$ (1), 141 (5), 129 (100), 115 (8), 91 (5), 77 (3), 41 (12). Anal. Calcd for $C_{18}H_{26}$: C, 89.19; H, 10.81. Found: C, 88.98; H, 10.65.

*(6-Bicyclo[4.2.2]deca-2,4,7,9-tetraen-7-yl-1-hexynyl)-trimethylsilane (**3e**).* Yield: 0.231 g (82%), colorless oil. R_f = 0.57. ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.25−6.30 (m, 1H), 6.18−6.24 (m, 1H), 5.73−5.81 (m, 2H), 5.64−5.72 (m, 2H), 5.44 (d, J = 6.1 Hz, 1H), 3.25 (dd, J = 8.7 Hz, J = 5.9 Hz, 1H), 3.16 (dt, J = 8.7 Hz, J = 6.0 Hz, 1H), 2.23 (t, J = 6.8 Hz, 2H), 2.13 (t, J = 7.2 Hz, 2H), 1.46−1.58 (m, 4H), 0.19 (s, 9H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): 141.9, 141.6, 135.9, 124.5, 124.0, 121.3, 121.0, 117.3, 107.5, 84.4, 39.2, 35.1, 34.4, 28.0 (2C), 19.7, 0.2 (3C) ppm. IR (liquid film): 3020, 2956, 2861, 2165, 1460, 1250 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{19}H_{26}Si$ $[M + H]^+$ 283.1881, found 283.1879. Anal. Calcd for $C_{19}H_{26}Si$: C, 80.78; H, 9.28; Si, 9.94. Found: C, 80.59; H, 9.11.

*(Bicyclo[4.2.2]deca-2,4,7,9-tetraen-7-yl)trimethylsilane (**3g**).* Yield: 0.168 g (83%), colorless oil. R_f = 0.54. ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.16−6.22 (m, 2H), 5.92 (d, J = 5.8 Hz, 1H), 5.69−5.81 (m, 4H), 3.39 (dd, J = 8.7 Hz, 5.9 Hz, 1H), 3.27 (dt, J = 8.8, 5.8 Hz, 1H), 0.12 (s, 9H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): 141.8, 140.2, 135.1, 128.9, 124.4, 123.9, 122.3, 121.3, 36.7, 35.8, −1.2 (3C) ppm. IR (liquid film): 3016, 2958, 2900, 1598, 1395, 1250 cm^{-1}. MS (EI, 70 eV) m/z (%): 202 $[M]^+$ (<1), 145 (1), 128 (67), 115 (2), 102 (2), 73 (100), 59 (13), 45 (16). Anal. Calcd for $C_{13}H_{18}Si$: C, 77.16; H, 8.97; Si, 13.88. Found: C, 76.94; H, 8.77.

*3-(Bicyclo[4.2.2]deca-2,4,7,9-tetraen-7-yl)-1-propanol (**3i**).* Yield: 0.160 g (85%), colorless oil. R_f = 0.65. ^{1}H NMR (400 MHz, CDCl3) δ 6.24−6.29 (m, 1H), 6.17−6.23 (m, 1H), 5.75−5.80 (m, 2H), 5.69−5.73 (m, 1H), 5.65 (dd, J = 8.5 Hz, J = 5.9 Hz, 1H), 5.46 (d, J = 6.1 Hz, 1H), 3.61 (t, J = 6.4 Hz, 2H), 3.26 (dd, J = 8.6 Hz, J = 6.0 Hz, 1H), 3.16 (dt, J = 8.5 Hz, J = 5.9 Hz, 1H), 2.13−2.24 (m, 2H), 1.63−1.76 (m, 4H) ppm. ^{13}C NMR (100 MHz, CDCl3) δ 141.9, 141.6, 135.7, 124.5, 124.0, 121.3, 121.0, 117.6, 62.5, 39.2, 35.0, 31.7, 31.2 ppm. IR (liquid film): 3350, 3012, 2933, 2865, 1394, 1037 cm^{-1}. MS (EI, 70 eV) m/z (%): 188 $[M]^+$ (<1), 141 (29), 128 (56), 115 (19), 91 (8), 77 (11), 65 (8), 51 (9), 40 (100). Anal. Calcd for $C_{13}H_{16}O$: C, 82.94; H, 8.57; O, 8.50. Found: C, 82.70; H, 8.41.

*4-(Bicyclo[4.2.2]deca-2,4,7,9-tetraen-7-yl)-1-butanol (**3j**).* Yield: 0.166 g (82%), colorless oil. R_f = 0.61. ^{1}H NMR (500 MHz, CDCl3) δ 6.24−6.30 (m, 1H), 6.17−6.23 (m, 1H), 5.73−5.79 (m, 2H), 5.69−5.72 (m, 1H), 5.65 (dd, J = 8.7 Hz, J = 5.8 Hz, 1H), 5.43 (d, J = 6.2 Hz, 1H), 3.64 (t, J = 6.2 Hz, 2H), 3.25 (dd, J = 8.7 Hz, J = 5.9 Hz, 1H), 3.16 (dt, J = 8.7 Hz, J = 5.9 Hz, 1H), 2.13 (t, J = 6.9 Hz, 2H), 1.45−1.63 (m, 4H) ppm. ^{13}C NMR (125 MHz, CDCl3) δ 142.0, 141.7, 136.0, 124.4, 123.9, 121.3, 121.0, 117.4, 62.9, 39.2, 35.0, 34.7, 32.3, 25.0 ppm. IR (liquid film): 3350, 3010, 2931, 2862, 1394, 1034 cm^{-1}. MS (EI, 70 eV) m/z (%): 202 $[M]^+$ (<1), 155 (3), 141 (26), 129 (100), 115 (19), 91 (11), 77 (9), 65 (6), 51 (6), 40 (56). Anal. Calcd for $C_{14}H_{18}O$: C, 83.12; H, 8.97; O, 7.91. Found: C, 82.96; H, 8.78.

*7-Phenyl-8-deuterobicyclo[4.2.2]deca-2,4,7,9-tetraene (**7**).* Yield: 0.149 g (72%), colorless oil. R_f = 0.65. ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.51 (d, J = 7.5 Hz, 2H), 7.41 (t, J = 7.7 Hz, 2H), 7.31 (dd, J = 15.1 Hz, J = 7.8 Hz, 1H), 6.44−6.50 (m, 1H), 6.37−6.43 (m, 1H), 5.91−5.97 (m, 3H), 5.82 (dd, J = 8.8 Hz, J = 5.8 Hz, 1H), 3.93 (dd, J = 8.6 Hz, J = 6.1 Hz, 1H), 3.45 (dd, J = 8.7 Hz, J = 5.8 Hz, 1H) ppm.^{13}C NMR (125 MHz, $CDCl_3$): δ 142.0, 141.1, 139.9, 135.1, 128.5 (2C), 126.8, 126.5 (2C), 124.9, 124.8, 121.6, 120.5, 119.5 (t, J_{CD} = 24.3 Hz), 38.3, 35.4 ppm. IR (liquid film): 3013, 2919, 1598, 1493, 1443, 1390

DOI: 10.1021/acs.joc.6b02540
J. Org. Chem. 2017, 82, 471−480

cm^{-1} MS (EI, 70 eV) *m/z* (%): 207 $[M]^+$ (100), 192 (38), 179 (18), 153 (10), 129 (94), 116 (21), 91 (85), 77 (41), 51 (35), 40 (49). Anal. Calcd for $C_{16}H_{13}D$: C, 92.71; H, 6.32; D, 0.97. Found: C, 92.55; H + D, 7.08.

Synthesis of 9,10-Dibromo-7-phenylbicyclo[4.2.2]deca-2,4,7-triene (4). From a dropping funnel for each, a solution of cycloadduct **3a** (3 mmol) in chloroform (8 mL) and bromine (3 mmol) in chloroform (8 mL) were added with vigorous stirring dropwise to 7 mL of chloroform under argon at −75 °C, After that the cooling bath was removed and chloroform was immediately removed under reduced pressure. Chromatographic purification over SiO_2 (100% petroleum ether as the eluent) afforded the target product **4**.

9,10-Dibromo-7-phenylbicyclo[4.2.2]deca-2,4,7-triene (4). Yield: 0.256 g (70%), colorless oil. R_f = 0.61. ^{1}H NMR (500 MHz, CDCl3) δ 7.32−7.40 (m, 5H), 6.24 (dd, *J* = 5.5 Hz, *J* = 1.0 Hz, 1H), 5.99−6.08 (m, 2H), 5.77−5.85 (m, 2H), 5.18−5.20 (m, 1H), 5.01 (dd, *J* = 5.4 Hz, *J* = 1.6 Hz, 1H), 4.28 (t, *J* = 7.0 Hz, 1H), 3.65−3.67 (m, 1H) ppm. ^{13}C NMR (125 MHz, CDCl3) δ 139.5, 139.1, 132.0, 130.3, 128.7 (2C), 128.5, 126.9, 126.5 (2C), 126.1, 123.1, 52.4, 51.0, 44.5, 43.3 ppm. IR (liquid film): 3024, 3016, 2918, 1602, 1484, 1435, 692, 678 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{16}H_{14}Br_2$ $[M + H]^+$ 364.9540, found 364.9538. Anal. Calcd for $C_{16}H_{14}Br_2$: C, 52.49; H, 3.85; Br, 43.65. Found: C, 52.24; H, 3.73; Br, 43.40.

Synthesis of Bicyclo[4.3.1]deca-2,4,8-triene-7,10-diols 5a−e, 6a−e, and 8 (General Procedure). At 0 °C, *m*-CPBA (2.8 mmol) was added to a mixture of cycloadducts **3a−f** and **7** (2 mmol) in dichloromethane (46 mL). The mixture was stirred for 3 h at 0 °C and for 12 h at room temperature. Then $NaHCO_3$ (4 mmol) was added, and after being stirred for 1 h at 0 °C, the mixture was washed with 1 M NaOH (23 mL) and brine (2 × 10 mL). The aqueous layer was extracted with dichloromethane (3 × 15 mL) and the combined organic solutions dried over $MgSO_4$, filtered, and concentrated. Purification by column chromatography on silica gel (petroleum ether → petroleum ether/ethyl acetate 5/1) afforded the target products **5**, **6a−e**, **8**.

*1-Phenylbicyclo[4.3.1]deca-2,4,8-triene-7,10-diol (**5a**).* Yield: 0.394 g (82%), white needles, mp 188−189 °C. R_f = 0.60. ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.35−7.48 (m, 5H), 6.53 (dd, *J* = 10.1 Hz, *J* = 5.4 Hz, 1H), 5.88−5.92 (m, 2H), 5.77−5.87 (m, 3H), 4.26 (s, 1H), 4.07 (dd, *J* = 10.5 Hz, *J* = 5.3 Hz, 1H), 3.42 (dd, *J* = 6.2 Hz, *J* = 1.8 Hz, 1H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 144.6, 134.0, 131.2, 130.4, 129.2 (2C), 128.0 (2C), 127.7, 125.6, 124.9, 123.6, 73.0, 65.3, 51.9, 47.1 ppm. IR (liquid film): 3400, 3020, 3011, 2951, 2870, 1578, 1495, 1441 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{16}H_{16}O_2$ $[M + H]^+$ 241.1228, found 241.1226. Anal. Calcd for $C_{16}H_{16}O_2$: C, 79.97; H, 6.71. Found: C, 79.79; H, 6.67.

*1-Butylbicyclo[4.3.1]deca-2,4,8-triene-7,10-diol (**5b**).* Yield: 0.176 g (40%), colorless oil. R_f = 0.58. ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.12 (dd, *J* = 10.0 Hz, *J* = 5.2 Hz, 1H), 5.74−5.81 (m, 2H), 5.60−5.65 (m, 1H), 5.55−5.57 (m, 2H), 4.08−4.11 (m, 2H), 3.27 (d, *J* = 4.3 Hz, 1H), 1.81−1.88 (m, 1H), 1.36−1.53 (m, 5H), 0.96 (t, *J* = 7.0 Hz, 3H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ 135.2, 130.6, 130.2, 126.0, 124.7, 123.9, 70.0, 66.5, 47.9, 45.3, 39.0, 25.5, 23.5, 14.1 ppm. IR (liquid film): 3440, 3020, 2956, 2860, 1722, 1427, 1254, 1028 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{14}H_{20}O_2$ $[M + H]^+$ 221.1541, found 221.1539. Anal. Calcd for $C_{14}H_{20}O_2$: C, 76.33; H, 9.15. Found: C, 76.22; H, 9.10.

*6-Butylbicyclo[4.3.1]deca-2,4,8-triene-7,10-diol (**6b**).* Yield: 0.176 g (40%), colorless oil. R_f = 0.48. ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.17 (ddd, *J* = 9.8 Hz, *J* = 5.5 Hz, *J* = 1.8 Hz, 1H), 5.93−5.97 (m, 1H), 5.87 (dd, *J* = 10.7 Hz, *J* = 7.0 Hz, 1H), 5.80 (dd, *J* = 12.3 Hz, *J* = 6.9 Hz, 1H), 5.49−5.53 (m, 1H), 5.27 (d, *J* = 12.3 Hz, 1H), 3.99 (s, 1H), 3.71 (s, 1H), 3.28 (dd, *J* = 9.0 Hz, *J* = 4.4 Hz, 1H), 2.13−2.19 (m, 1H), 1.51−1.57 (m, 1H), 1.33−1.40 (m, 4H), 0.95 (t, *J* = 5.6 Hz, 3H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 136.4, 129.7, 128.0, 126.2, 123.75, 121.5, 70.8, 70.0, 47.8, 44.9, 34.6, 25.5, 23.5, 14.2 ppm. IR (liquid film): 3400, 3025, 2957, 2874, 1719, 1427, 1255, 1030 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{14}H_{20}O_2$ $[M + H]^+$ 221.1541, found 221.1538. Anal. Calcd for $C_{14}H_{20}O_2$: C, 76.33; H, 9.15. Found: 76.19; H, 9.11.

*1-Hexylbicyclo[4.3.1]deca-2,4,8-triene-7,10-diol (**5c**).* Yield: 0.203 g (41%), colorless oil. R_f = 0.52. ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.13 (dd, *J* = 10.0 Hz, *J* = 5.2 Hz, 1H), 5.75−5.84 (m, 2H), 5.55−5.66 (m, 2H), 5.38 (dd, *J* = 9.8 Hz, *J* = 1.0 Hz, 1H), 4.09−4.13 (m, 2H), 3.28−3.32 (m, 1H), 1.81−1.87 (m, 1H), 1.33−1.50 (m, 9H), 0.92 (t, *J* = 7.0 Hz, 3H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 135.2, 130.6, 130.3, 126.0, 124.7, 123.9, 70.1, 66.5, 48.0, 45.3, 39.2, 31.8, 30.1, 23.3, 22.7, 14.1 ppm. IR (liquid film): 3440, 3021, 2957, 2865, 1726, 1427, 1256, 1028 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{16}H_{24}O_2$ $[M + H]^+$ 249.1854, found 249.1850. Anal. Calcd for $C_{16}H_{24}O_2$: C, 77.38; H, 9.74. Found: C, 77.23; H, 9.68.

*6-Hexylbicyclo[4.3.1]deca-2,4,8-triene-7,10-diol (**6c**).* Yield: 0.198 g (40%), colorless oil. R_f = 0.46. ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.17 (ddd, *J* = 9.8 Hz, *J* = 5.5 Hz, *J* = 1.8 Hz, 1H), 5.94−5.98 (m, 1H), 5.87 (dd, *J* = 10.7 Hz, *J* = 6.9 Hz, 1H), 5.80 (dd, *J* = 12.3 Hz, *J* = 7.0 Hz, 1H), 5.51−5.54 (m, 1H), 5.26 (d, *J* = 12.3 Hz, 1H), 4.01 (s, 1H), 3.72 (s, 1H), 3.28 (dd, *J* = 8.9 Hz, *J* = 4.4 Hz, 1H), 2.13−2.19 (m, 1H), 1.51−1.56 (m, 1H), 1.27−1.37 (m, 8H), 0.91 (t, *J* = 7.0 Hz, 3H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 136.5, 129.7, 128.0, 126.2, 123.8, 121.5, 70.9, 70.0, 47.8, 44.9, 34.8, 31.9, 30.1, 23.2, 22.7, 14.1 ppm. IR (liquid film): 3400, 3020, 2951, 2872, 1715, 1427, 1250, 1030. HRMS (ESI-TOF): calcd for $C_{16}H_{24}O_2$ $[M + H]^+$ 249.1854, found 249.1852. Anal. Calcd for $C_{16}H_{24}O_2$: C, 77.38; H, 9.74. Found: C, 77.27; H, 9.70.

*1-Octylbicyclo[4.3.1]deca-2,4,8-triene-7,10-diol (**5d**).* Yield: 0.221 g (40%), colorless oil. R_f = 0.58. ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.12 (dd, *J* = 10.0 Hz, *J* = 5.2 Hz, 1H), 5.75−5.82 (m, 2H), 5.61−5.66 (m, 1H), 5.55−5.57 (m, 1H), 5.37 (dd, *J* = 10.0 Hz, *J* = 1.4 Hz, 1H), 4.08−4.12 (m, 2H), 3.28 (dd, *J* = 6.3 Hz, *J* = 2.4 Hz, 1H), 1.81−1.86 (m, 1H), 1.41−1.49 (m, 1H), 1.29−1.40 (m, 12H), 0.90 (t, *J* = 6.9 Hz, 3H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 135.2, 130.6, 130.3, 126.0, 124.7, 123.9, 70.1, 66.5, 48.0, 45.3, 39.2, 31.9, 30.5, 29.6, 29.3, 23.4, 22.7, 14.1 ppm. IR (liquid film): 3440, 3025, 2959, 2866, 1720, 1427, 1250, 1025 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{18}H_{28}O_2$ $[M + H]^+$ 277.2167, found 277.2165. Anal. Calcd for $C_{18}H_{28}O_2$: C, 78.21; H, 10.21. Found: C, 78.09; H, 10.18.

*6-Octylbicyclo[4.3.1]deca-2,4,8-triene-7,10-diol (**6d**).* Yield: 0.215 g (39%), as colorless oil. R_f = 0.47. ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.16 (ddd, *J* = 9.8 Hz, *J* = 5.5 Hz, *J* = 1.7 Hz, 1H), 5.93−5.97 (m, 1H), 5.87 (dd, *J* = 10.7 Hz, *J* = 7.0 Hz, 1H), 5.79 (dd, *J* = 12.3 Hz, *J* = 6.9 Hz, 1H), 5.51 (dd, *J* = 9.8 Hz, *J* = 4.1 Hz, 1H), 5.25 (d, *J* = 12.3 Hz, 1H), 4.00 (s, 1H), 3.70 (d, *J* = 5 Hz, 1H), 3.28 (dd, *J* = 8.9 Hz, *J* = 4.4 Hz, 1H), 2.13−2.18 (m, 1H), 1.50−1.55 (m, 1H), 1.29−1.40 (m, 12H), 0.90 (t, *J* = 6.9 Hz, 3H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 136.5, 129.7, 128.0, 126.2, 123.8, 121.5, 70.8, 70.0, 47.8, 44.9, 34.8, 31.9, 30.5, 29.7, 29.4, 23.3, 22.7, 14.1 ppm. IR (liquid film): 3400, 3020, 2950, 2871, 1721, 1430, 1258, 1030 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{18}H_{28}O_2$ $[M + H]^+$ 277.2167, found 277.2164. Anal. Calcd for $C_{18}H_{28}O_2$: C, 78.21; H, 10.21. Found: C, 78.06; H, 10.19.

*1-[6-(Trimethylsilyl)-5-hexynyl]bicyclo[4.3.1]deca-2,4,8-triene-7,10-diol (**5e**).* Yield: 0.247 g (39%), colorless oil. R_f = 0.55. ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.14 (dd, *J* = 10.0 Hz, *J* = 5.2 Hz, 1H), 5.77−5.79 (m, 2H), 5.62−5.66 (m, 1H), 5.55−5.57 (m, 1H), 5.36 (dd, *J* = 10.0 Hz, *J* = 1.3 Hz, 1H), 4.15 (s, 1H), 4.07 (d, *J* = 4.9 Hz, 1H), 3.29 (dd, *J* = 6.3 Hz, *J* = 2.3 Hz, 1H), 2.32 (t, *J* = 6.2 Hz, 2H), 1.85−1.88 (m, 1H), 1.46−1.64 (m, 5H), 0.90 (s, 9H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 134.8, 130.4, 130.2, 126.4, 124.9, 123.8, 107.2, 85.3, 70.0, 66.5, 47.9, 45.2, 37.8, 28.2, 21.8, 19.2, 0.1 (3C) ppm. IR (liquid film): 3447, 3030, 2954, 2862, 2170, 1435, 1248, 1042 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{19}H_{28}O_2Si$ $[M + H]^+$ 317.1936, found 317.1933. Anal. Calcd for $C_{19}H_{28}O_2Si$: C, 72.10; H, 8.92. Found: C, 71.89; H, 8.88.

*6-[6-(Trimethylsilyl)-5-hexynyl]bicyclo[4.3.1]deca-2,4,8-triene-7,10-diol (**6e**).* 0.247 g (39%), colorless oil. R_f = 0.35. ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.17 (ddd, *J* = 9.9 Hz, *J* = 5.5 Hz, *J* = 1.7 Hz, 1H), 5.94−5.98 (m, 1H), 5.87 (dd, *J* = 10.7 Hz, *J* = 7.0 Hz, 1H), 5.80 (dd, *J* = 12.3 Hz, *J* = 7.0 Hz, 1H), 5.50−5.53 (m, 1H), 5.26 (d, *J* = 12.3 Hz, 1H), 4.02 (s, 1H), 3.71 (s, 1H), 3.29 (dd, *J* = 8.9 Hz, *J* = 4.4 Hz, 1H), 2.30 (t, *J* = 7.0 Hz, 2H), 2.14−2.18 (m, 1H), 1.47−1.62 (m, 5H), 0.16 (s, 9H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 136.1, 129.8, 128.0, 126.2, 123.9, 121.4, 107.5, 84.8, 70.8, 70.0, 47.9, 44.8, 33.8, 28.8, 22.1,

DOI: 10.1021/acs.joc.6b02540
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19.6, 0.2 (3C) ppm. IR (liquid film): 3440, 3030, 2954, 2857, 2173, 1440, 1251, 1042. HRMS (ESI-TOF): calcd for $C_{19}H_{28}O_2Si$ $[M + H]^+$ 317.1936, found 317.1935. Anal. Calcd for $C_{19}H_{28}O_2Si$: C, 72.10; H, 8.92. Found: C, 71.93; H, 8.86.

*1-Phenyl-10-deuterobicyclo[4.3.1]deca-2,4,8-triene-7,10-diol (**8**).* Yield: 0.386 g (80%), colorless oil, R_f = 0.55. ^1H NMR (500 MHz, $CDCl_3$): δ 7.41−7.54 (m, 4H), 7.34−7.38 (m, 1H), 6.50 (dd, J = 10.2 Hz, J = 5.2 Hz, 1H), 6.16 (d, J = 10.2 Hz, 1H), 5.95−6.00 (m, 2H), 5.88−5.93 (m, 2H), 5.46 (d, J = 5.1 Hz, 1H), 3.47 (d, J = 6.0 Hz, 1H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 145.1, 135.0, 131.4, 130.7, 128.8 (2C), 127.8 (2C), 127.3, 125.1, 124.8, 124.1, 70.2 (t, J_{CD} = 23.0 Hz), 66.6, 51.8, 45.6 ppm. Anal. Calcd for: C, 79.64; H, 6.27; D, 0.83. Found: C, 79.45; H+D, 7.04. IR (liquid film): 3468, 3012, 2919, 1601, 1492, 1443, 1390 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{16}H_{15}DO_2$ $[M + H]^+$ 242.1290, found 242.1288. Anal. Calcd for $C_{16}H_{15}DO_2$: C, 79.64; H, 6.27; D, 0.83. Found: C, 79.45; H+D, 7.04.

Synthesis of Tricyclic Alcohols 9h−j and 10j (General Procedure). At 0 °C, *m*-CPBA (2.8 mmol) was added to a mixture of cycloadducts **3h−j** (2 mmol) in chloroform (46 mL). The mixture was stirred for 3 h at 0 °C, for 3 h at 40 °C, and for 12 h at room temperature. Then $NaHCO_3$ (4 mmol) was added, and after it was stirred for 1 h at 0 °C, the mixture was washed with 1 M NaOH (23 mL) and brine (2 × 10 mL). The aqueous layer was extracted with dichloromethane (3 × 15 mL), and the combined organic solutions were dried over $MgSO_4$, filtered, and concentrated. Purification by column chromatography on silica gel (petroleum ether → petroleum ether/ethyl acetate 1/1) afforded the target products **9h−j** and **10j**.

*4-Oxatricyclo[6.4.1.0^{1,5}]trideca-6,9,11-trien-13-ol (**9h**).* Yield: 0.274 g (72%), colorless oil. R_f = 0.66. ^1H NMR (500 MHz, $CDCl_3$): δ 6.16 (ddd, J = 9.8 Hz, J = 4.6 Hz, J = 1.7 Hz, 1H), 5.83−5.92 (m, 2H), 5.75−5.78 (m, 2H), 5.41−5.45 (m, 1H), 4.12−4.17 (m, 1H), 3.86−3.95 (m, 3H), 3.38 (t, J = 6.8 Hz, 1H), 2.63−2.66 (m, 1H), 2.13−2.20 (m, 1H)) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 135.1, 129.4, 128.8, 124.7, 124.3, 122.5, 78.3, 71.0, 68.4, 50.6, 45.5, 38.5 ppm. IR (liquid film): 3493, 3025, 2967, 2853, 1608, 1440, 1391, 1259 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{12}H_{14}O_2$ $[M + H]^+$ 191.1071, found 191.1068. Anal. Calcd for $C_{12}H_{14}O_2$: C, 75.76; H, 7.42. Found: C, 75.57; H, 7.32.

*5-Oxatricyclo[7.4.1.0^{1,6}]tetradeca-7,10,12-trien-14-ol (**9i**).* Yield: 0.282 g (69%), white needles, mp 80−81 °C. R_f = 0.63. ^1H NMR (500 MHz, $CDCl_3$): δ 6.08 (ddd, J = 9.8 Hz, J = 5.6 Hz, J = 1.9 Hz, 1H), 6.00 (t, J = 10.0 Hz, 1H), 5.82 (dd, J = 10.7 Hz, J = 7.1 Hz, 1H), 5.69−5.73 (m, 1H), 5.66 (dd, J = 9.7 Hz, J = 4.3 Hz, 1H), 5.09 (d, J = 12.4 Hz, 1H), 3.91 (d, J = 10.7 Hz, 1H), 3.66−3.68 (m, 1H), 3.54 (ddd, J = 12.9 Hz, J = 11.5 Hz, J = 2.9 Hz, 2H), 3.29 (dd, J = 9.1 Hz, J = 4.4 Hz, 1H), 2.36−2.46 (m, 1H), 2.13−2.17 (m, 1H), 1.87−1.94 (m, 1H), 1.53−1.57 (m, 1H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 137.4, 130.9, 125.5, 124.7, 124.3, 123.4, 75.4, 74.9, 68.2, 46.3, 42.0, 35.6, 22.5 ppm. IR (liquid film): 3495, 3028, 2963, 2850, 1608, 1440, 1395, 1259 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{13}H_{16}O_2$ $[M + H]^+$ 205.1228, found 205.1223. Anal. Calcd for $C_{13}H_{16}O_2$: C, 76.44; H, 7.90. Found: C, 76.23; H, 7.68.

*6-Oxatricyclo[8.4.1.0^{1,7}]pentadeca-8,11,13-trien-15-ol (**9j**).* Yield: 0.227 g (52%), white needles, mp 56−57 °C. R_f = 0.61. ^1H NMR (500 MHz, $CDCl_3$): δ 6.01−6.04 (m, 1H), 5.93 (t, J = 8.2 Hz, 1H), 5.82 (dd, J = 10.8 Hz, J = 7.0 Hz, 1H), 5.68 (dd, J = 12.2 Hz, J = 7.0 Hz, 1H), 5.57 (dd, J = 9.8 Hz, J = 4.7 Hz, 1H), 5.46 (d, J = 12.2 Hz, 1H), 4.16 (dd, J = 13.0 Hz, J = 3.5 Hz, 1H), 3.67 (d, J = 5.6 Hz, 1H), 3.57 (d, J = 8.9 Hz, 1H), 3.38−3.44 (m, 2H), 2.34−2.39 (m, 1H), 1.88−1.92 (m, 1H), 1.71−1.83 (m, 4H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 135.1, 130.2, 125.6, 125.2, 123.2, 121.1, 79.5, 75.5, 72.2, 48.1, 45.0, 36.6, 34.1, 22.0 ppm. IR (liquid film): 3494, 3027, 2960, 2849, 1608, 1440, 1397, 1260 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{14}H_{18}O_2$ $[M + H]^+$ 219.1384, found 219.1380. Anal. Calcd for $C_{14}H_{18}O_2$: C, 77.03; H, 8.31. Found: C, 76.84; H, 8.25.

*2-Oxatricyclo[5.5.2.1^{7,12}]pentadeca-8,10,13-trien-15-ol (**10j**).* Yield: 0.057 g (13%), white needles, mp 59−60 °C. R_f = 0.63. ^1H NMR (500 MHz, $CDCl_3$): δ 6.20 (dd, J = 10.1 Hz, J = 5.3 Hz, 1H), 5.77−5.81 (m, 2H), 5.59−5.65 (m, 1H), 5.52−5.58 (m, 1H), 5.41 (dd, J = 10.1 Hz, J = 1.4 Hz, 1H), 3.90 (d, J = 10.1 Hz, 1H), 3.84 (d, J = 5.1 Hz, 1H), 3.74 (ddd, J = 11.4 Hz, J = 9.0 Hz, J = 2.5 Hz, 1H), 3.39−3.43 (m, 1H), 3.22−3.23 (m, 1H), 1.92−1.98 (m, 2H), 1.82−1.89 (m, 1H), 1.47−1.65 (m, 2H), 1.37 (td, J = 12.5 Hz, J = 2.5 Hz, 1H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 136.5, 132.5, 130.6, 125.3, 124.2, 122.0, 72.4, 69.9, 65.3, 45.8, 45.7, 38.0, 28.7, 18.4 ppm. IR (liquid film): 3455, 3020, 2954, 2843, 1608, 1440, 1391, 1260 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{14}H_{18}O_2$ $[M + H]^+$ 219.1384, found 219.1383. Anal. Calcd for $C_{14}H_{18}O_2$: C, 77.03; H, 8.31. Found: C, 76.89; H, 8.27.

Synthesis of Bicyclo[4.3.1]deca-2,4,8-triene-7,10-diones 11a−e and 12b,d (General Procedure). A suspension of 4.3 g of CrO_3·2(pyridine) in 71.7 mL of CH_2Cl_2 was cooled to 0 °C. Then to the suspension was added 1.5 mmol of **5a,b,d,e** or **6b,d** in 1.4 mL of CH_2Cl_2 with vigorous stirring. Stirring was continued for 1 h at 0−20 °C. Then the reaction mixture was filtered. The filtrate was washed with saturated $NaHCO_3$, dried ($MgSO_4$), and concentrated under reduced pressure. Purification by column chromatography on silica gel (petroleum ether → petroleum ether/ethyl acetate 10/1) afforded the target products **11a,b,d,e** and **12b,d**.

*1-Phenylbicyclo[4.3.1]deca-2,4,8-triene-7,10-dione (**11a**).* Yield: 0.329 g (93%), colorless oil. R_f = 0.47. ^1H NMR (500 MHz, $CDCl_3$): δ 7.28−7.46 (m, 5H), 7.10 (d, J = 10.2 Hz, 1H), 6.84 (d, J = 10.1 Hz, 1H), 6.29 (dd, J = 11.1 Hz, J = 7.8 Hz, 1H), 6.22 (dd, J = 10.9 Hz, J = 7.9 Hz, 1H), 6.15 (d, J = 11.2 Hz, 1H), 5.70 (dd, J = 10.9 Hz, J = 7.6 Hz, 1H), 4.42 (d, J = 7.6 Hz, 1H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 196.7, 192.6, 146.8, 138.9, 131.0, 130.7, 128.5 (2C), 128.3, 128.2 (2C), 126.9, 126.1, 125.0, 69.6, 61.2 ppm. IR (liquid film): 3026, 3015, 2930, 1671, 1492, 1443 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{16}H_{12}O_2$ $[M + H]^+$ 237.0915, found 237.0914. Anal. Calcd for $C_{16}H_{12}O_2$: C, 81.34; H, 5.12. Found: C, 81.08; H, 4.98.

*1-Butylbicyclo[4.3.1]deca-2,4,8-triene-7,10-dione (**11b**).* Yield: 0.308 g (95%), colorless oil. R_f = 0.50. ^1H NMR (500 MHz, $CDCl_3$): δ 6.74 (d, J = 10.0 Hz, 1H), 6.57 (d, J = 10.5 Hz, 1H), 6.06−6.17 (m, 2H), 5.63 (d, J = 10.5 Hz, 1H), 5.52−5.56 (m, 1H), 4.32 (d, J = 7.3 Hz, 1H), 2.37−2.44 (m, 1H), 1.63−1.68 (m, 1H), 1.29−1.39 (m, 2H), 1.09−1.16 (m, 2H), 0.89 (t, J = 6.9 Hz, 3H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 198.6, 193.3, 148.5, 132.1, 130.0, 126.1, 125.8, 124.7, 70.3, 56.1, 35.7, 26.7, 23.1, 13.8 ppm. IR (liquid film): 3025, 2952, 2864, 1725, 1693, 1421, 1249, 1025 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{14}H_{16}O_2$ $[M + H]^+$ 217.1228, found 217.1225. Anal. Calcd for $C_{14}H_{16}O_2$: C, 77.75; H, 7.46. Found: C, 77.57; H, 7.33.

*1-Octylbicyclo[4.3.1]deca-2,4,8-triene-7,10-dione (**11d**).* Yield: 0.400 g (98%), colorless oil. R_f = 0.45. ^1H NMR (500 MHz, $CDCl_3$): δ 6.72 (d, J = 10.1 Hz, 1H), 6.56 (d, J = 10.1 Hz, 1H), 6.05−6.12 (m, 2H), 5.61 (d, J = 10.6 Hz, 1H), 5.52−5.56 (m, 1H), 4.32 (d, J = 7.3 Hz, 1H), 2.36−2.42 (m, 1H), 1.62−1.68 (m, 1H), 1.26−1.32 (m, 10H), 1.10−1.16 (m, 2H), 0.89 (t, J = 6.9 Hz, 3H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 198.6, 193.3, 148.5, 132.2, 130.0, 126.1, 125.8, 124.7, 70.2, 56.1, 35.9, 31.8, 30.0, 29.3, 29.2, 24.5, 22.6, 14.1 ppm. IR (liquid film): 3025, 2960, 2861, 1728, 1693, 1425, 1249, 1026 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{18}H_{24}O_2$ $[M + H]^+$ 273.1854, found 273.1850. Anal. Calcd for $C_{18}H_{24}O_2$: C, 79.37; H, 8.88. Found: C, 79.19; H, 8.63.

*1-[6-(Trimethylsilyl)-5-hexynyl]bicyclo[4.3.1]deca-2,4,8-triene-7,10-dione (**11e**).* Yield: 0.431 g (92%), colorless oil. R_f = 0.51. ^1H NMR (500 MHz, $CDCl_3$): δ 6.73 (d, J = 10.1 Hz, 1H), 6.56 (d, J = 10.1 Hz, 1H), 6.05−6.12 (m, 2H), 5.59−5.62 (m, 1H), 5.52−5.56 (m, 1H), 4.31 (d, J = 7.2 Hz, 1H), 2.35−2.42 (m, 1H), 2.16−2.29 (m, 2H), 1.65−1.73 (m, 1H), 1.46−1.62 (m, 2H), 1.21−1.35 (m, 2H), 0.15 (s, 9H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 198.4, 193.1, 148.3, 131.9, 130.1, 126.2, 125.8, 124.7, 106.8, 85.0, 70.2, 56.0, 35.2, 28.6, 23.5, 19.5, 0.1 (3C) ppm. IR (liquid film): 3030, 2954, 2862, 2173, 1694, 1430, 1249, 1040 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{19}H_{24}O_2Si$ $[M + H]^+$ 313.1623, found 313.1622. Anal. Calcd for $C_{19}H_{24}O_2Si$: C, 73.03; H, 7.74. Found: C, 72.91; H, 7.49.

*6-Butylbicyclo[4.3.1]deca-2,4,8-triene-7,10-dione (**12b**).* Yield: 0.308 g (95%), colorless oil. R_f = 0.33. ^1H NMR (500 MHz, $CDCl_3$): δ 6.82 (dd, J = 10.0 Hz, J = 5.0 Hz, 1H), 6.51 (d, J = 9.8 Hz, 1H), 6.15 (dd, J = 10.7 Hz, J = 7.5 Hz, 1H), 6.01−6.06 (m, 2H), 5.24 (d, J = 11.5 Hz, 1H), 3.97 (dd, J = 9.1 Hz, J = 4.9 Hz, 1H), 2.14−2.20 (m, 1H), 2.05−2.11 (m, 1H), 1.36−1.44 (m, 2H), 1.16−1.31 (m, 2H),

DOI: 10.1021/acs.joc.6b02540
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0.89 (t, J = 7.3 Hz, 3H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 198.6, 194.4, 140.9, 131.8, 130.0, 127.2, 125.5, 123.8, 74.2, 51.7, 29.8, 27.3, 23.5, 14.0 ppm. IR (liquid film): 3024, 2955, 2870, 1710, 1695, 1429, 1253, 1032 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{14}H_{16}O_2$ $[M + H]^+$ 217.1228, found 217.1226. Anal. Calcd for $C_{14}H_{16}O_2$: C, 77.75; H, 7.46. Found: C, 77.47; H, 7.36.

6-Octylbicyclo[4.3.1]deca-2,4,8-triene-7,10-dione (**12d**). Yield: 0.396 g (97%), colorless oil. R_f = 0.40. ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.81 (dd, J = 10.1 Hz, J = 5.0 Hz, 1H), 6.50 (d, J = 9.7 Hz, 1H), 6.15 (dd, J = 10.7 Hz, J = 7.5 Hz, 1H), 6.00−6.05 (m, 2H), 5.23 (d, J = 11.5 Hz, 1H), 3.97 (dd, J = 9.1 Hz, J = 4.9 Hz, 1H), 2.13−2.19 (m, 1H), 2.03−2.09 (m, 1H), 1.22−1.39 (m, 12H), 0.89 (t, J = 7.0 Hz, 3H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ 198.6, 194.4, 140.9, 131.9, 130.0, 127.2, 125.5, 123.8, 74.2, 51.7, 31.9, 30.4, 30.0, 29.4, 29.3, 25.1, 22.7, 14.1 ppm. IR (liquid film): 3020, 2955, 2870, 1732, 1688, 1430, 1245, 1026 cm^{-1}. HRMS (ESI-TOF): calcd for $C_{18}H_{24}O_2$ $[M + H]^+$ 273.1854, found 273.1851. Anal. Calcd for $C_{18}H_{24}O_2$: C, 79.37; H, 8.88. Found: C, 79.10; H, 8.79.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.6b02540.

Spectral data for all new compounds, crystal data for **5a** and **9i**, and cell culture and apoptosis analysis procedure (PDF)

Crystallographic data for **5a** (CIF)

Crystallographic data for **9i** (CIF)

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

Financial support was received from the Russian Foundation for Basic Research (Grants 15-03-01254, 15-33-20043, 16-33-00379). The structural studies of the synthesized compounds were performed with the use of Collective Usage Centre "Agidel" at the Institute of Petrochemistry and Catalysis of RAS. The biological studies of bicycles were done at the Center for Molecular Design and Drug Bioscreening at the Institute of Petrochemistry and Catalysis of RAS that was created with the financial support of the Russian Science Foundation. HMRS data were recorded at the Department of Structural Studies of Zelinsky Institute of Organic Chemistry, Moscow.

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DOI: 10.1021/acs.joc.6b02540
J. Org. Chem. 2017, 82, 471−480